

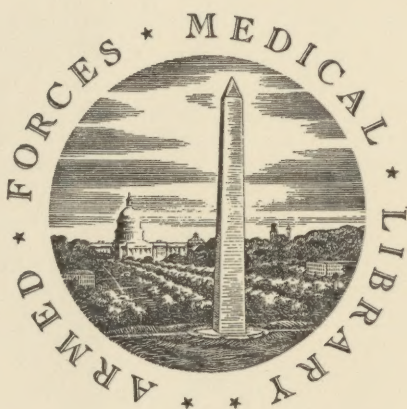


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SURGERY IN WORLD WAR II

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VASCULAR SURGERY

Edited by

DANIEL C. ELKIN, M. D.

MICHAEL E. DeBAKEY, M. D.

OFFICE OF THE SURGEON GENERAL

DEPARTMENT OF THE ARMY

WASHINGTON, D. C., 1955

The volumes comprising the history of the Medical Department of the United States Army in World War II are divided into two series: (1) The Administrative and Operational series which constitutes a part of the general series of the history of the *United States Army in World War II*, published under the direction of the Office of the Chief of Military History, and (2) the Professional, or clinical and technical, series published as *The Medical Department of the United States Army* under the direction of the Office of The Surgeon General. Both series are being prepared by the Historical Unit, Army Medical Service. This is one of a number of volumes to be published in the latter series.

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VASCULAR SURGERY IN WORLD WAR II

Edited by

DANIEL C. ELKIN, M. D.

MICHAEL E. DeBAKEY, M. D.

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This volume was prepared by the Historical Unit, Army Medical Service, under the direction of Colonel Calvin H. Goddard, MC, AUS, formerly Editor in Chief; Associate Editor for Vascular Surgery, Helen Orr.

Foreword

The group of historical volumes now in preparation upon the activities of the United States Army Medical Department in World War II constitutes the third series of such works devoted to recording the formal history of that department under war conditions. The first such series, published over the years 1870-88, comprised six ponderous tomes, three of medicine and three of surgery, which appeared under the title *Medical and Surgical History of the War of the Rebellion*. The second, following World War I, embraced fifteen volumes published in seventeen parts (1921-29). This series was entitled *History of the Medical Department of the United States Army in the World War*. Two volumes of the seventeen dealt with surgical matters.

The present treatise, Vascular Surgery, is among the first of the third series to receive publication. It will offer mute but convincing testimony to the vast progress recently recorded in the field whereof it treats. Not that vascular surgery, per se, is a new phenomenon. In its simplest form, ligation, it was practiced in the American Civil War on a great many more occasions than is generally known. Thus, in 672 recorded operations for wounds of the face alone, no less than 69 involved ligation of an artery or vein—the common carotid artery figuring in 55 of these. Based on cases whose dispositions were known, mortality for the entire series was 65 percent, for cases involving the common carotid about 72 percent, and but 6 of the 65 patients operated upon (3 of these, common carotid cases) were later able to return to duty.

Despite the amount of space accorded other surgical specialties in our World War I medical history (e. g., 535 pages on neurosurgery in one of the surgical volumes), vascular surgery is there dismissed with a single paragraph. As a result, the meteoric expansion of activity in that field to the point where its adequate discussion in World War II records calls for an entire volume, becomes especially significant. Truly, vascular surgery has come of age.

GEORGE E. ARMSTRONG
Major General, United States Army
The Surgeon General

Preface

The history of injuries produced by war wounds is in effect the history of surgery. A surgical record of World War II is therefore no innovation except that certain features are now for the first time receiving substantial recognition and treatment. One of these features concerns vascular surgery.

This volume does not purport to be a complete record of casualties with vascular injuries in World War II. Data from many of the theaters of operations are unavailable—notably China-Burma-India, Southwest Pacific, and Pacific Ocean Areas, and records from the North African, Mediterranean, and European theaters are far from complete. Under battle conditions, the existence of vascular injuries was often masked by more extensive injuries to bone and soft tissue. Furthermore, many deaths on the battlefield which might rightfully have been attributable to wounds of the major arteries were not so recorded.

This volume *does* purport to give a reasonably complete accounting of complications which followed combat-incurred vascular injuries in casualties evacuated to the Zone of Interior. It also includes an accounting of peripheral vascular disorders observed in Army personnel during World War II, with the exception of trenchfoot, immersion foot, and cold injuries, which will be discussed in a separate volume in the Medical History series.

The principles of vascular surgery have been established for many years, and in the interim between World Wars I and II many significant technical advances were made. Vascular injuries, however, are relatively infrequent in civilian life, and few surgeons, even those particularly interested in the subject, had had a large experience with them.

The problem of supplying competent specialized care for the numbers of casualties with these injuries was, therefore, a difficult one. It was solved in World War II by the establishment of three vascular centers to which surgeons experienced in this specialty were attached.

It is to the credit of Surgeon General James C. McGee and his successor, Surgeon General Norman T. Kirk, that these centers were inaugurated soon after the first casualties began to arrive in this country. The chief consultant in surgery, Brigadier General Fred W. Rankin, by his untiring efforts in securing and holding trained personnel and in procuring proper equipment, was responsible in a large measure for the success of this undertaking. In this he had the understanding aid of his assistants, Colonel B. N. Carter, MC, and Colonel Michael E. DeBakey, MC. For the first time in history there was a concentration of clinical material under the supervision of specialists who could carry out concurrently definitive treatment and important phases of clinical investigation.

As a result, knowledge regarding the circulatory system has been extended and interest has been generated in a field which, though long recognized, has attracted few workers.

The lessons learned, as reflected in the low mortality rate and the remarkable functional results achieved in these centers, came not by chance but through careful planning and execution. Those who had part in it prayerfully hope that these lessons will not soon be forgotten.

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Emory University, Ga.
28 May 1954.

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CHAPTER I

Specialized Centers for the Management of Vascular Injuries and Diseases

*Daniel C. Elkin, M. D.**

The arrest of hemorrhage and the preservation of an adequate arterial supply to injured extremities have been the primary concern of military surgeons in all the wars of history. In each successive war the relative number of vascular injuries has steadily become larger because the development of weapons of increasingly higher velocity has magnified the chances of vascular trauma.

During World War II, as a result of widespread use of weapons of such type, multiple wounds were more frequent. Dozens of nonfatal wounds were often observed in the same casualty and as high as two hundred wounds have been recorded. Furthermore, while case fatality and amputation rates were high in injuries of the major arteries, improved methods for the control of hemorrhage, shock, and infection greatly decreased the incidence of death and mutilation and increased the numbers of casualties who lived with possible post-traumatic complications.

The medical records of World War I supplied almost no information about vascular injuries in American military personnel. Early in World War II it became evident that this type of injury was likely to be frequent and would create grave problems. While the principles of vascular surgery had been established for many years, and prior to the outbreak of World War II many significant advances had been made in this field, the fact remained that wounds of this type occurred infrequently in civilian life and that surgeons with extensive experience in this specialty were few.

ESTABLISHMENT OF VASCULAR CENTERS IN THE ZONE OF INTERIOR¹

The problem of supplying competent specialized care by experienced personnel for large numbers of casualties with vascular injuries was solved in World War II by the establishment in the Zone of Interior of vascular centers² to which surgeons experienced in vascular surgery were attached and in which

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¹ Unless otherwise specified, all data contained in this chapter are derived from reports prepared for this purpose by J. W. Kahn (formerly Captain, MC, Ashford General Hospital), H. B. Shumacker, Jr. (formerly Lt. Colonel, MC, Mayo General Hospital), and A. H. Storck (formerly Lt. Colonel, MC, DeWitt General Hospital).

² WD Memo W40-14-43, 28 May 43.

other surgeons could be trained. To these centers were sent patients with vascular injuries and diseases.

The establishment of these centers made it possible to carry out the necessary treatment of such patients with an economy of equipment, personnel, and effort which would have been impossible had the patients been scattered through a large number of hospitals. It also permitted the observation of patients with vascular injury and disease in numbers far beyond those of any similar previous experience. Careful and detailed records were kept and analysis of data derived therefrom permitted deductions and conclusions which could not be gained from the small series of cases previously observed by surgeons in civilian practice.

The first vascular centers to be activated were located at Ashford General Hospital, White Sulphur Springs, W. Va., and Letterman General Hospital, San Francisco, Calif. These centers were established by a War Department memorandum dated 28 May 1943.³ The former center continued in operation throughout the war and was not deactivated until 30 June 1946.⁴ The author of this chapter served as chief of the vascular surgical section throughout the period of operation.

The vascular center established at Letterman was active until 23 December 1943⁵ and the patients on the vascular ward at the time were transferred to Torney General Hospital, Palm Springs, Calif., which had been officially designated a vascular center 17 December 1943.⁶ Lt. Col. Russell H. Patterson served as chief of the center during the 7 months period of activity at Letterman. Torney General Hospital continued to house the vascular center until 12 June 1944 when DeWitt General Hospital, Auburn, Calif., was officially designated as a hospital to which patients with vascular disorders should be sent.⁷ Capt. (later Major) LeRoy J. Kleinsasser served as chief of the vascular surgical section at both Torney and DeWitt General Hospitals.⁸ He held this position until May 1945 when he was succeeded by Maj. (later Lt. Colonel) Norman E. Freeman who served until the center was deactivated.⁹

Early in 1944 the influx of patients with vascular disabilities from the European and Aleutian theaters reached a point where it became necessary to establish another center for patients with vascular disorders. A third vascular center was therefore designated at Percy Jones General Hospital, Battle Creek, Mich., 12 June 1944.¹⁰ This center was active only a short time for on 25 August 1944 Mayo General Hospital, Galesburg, Ill., was designated a vascular center and all patients and personnel were transferred from Percy Jones to

³ See footnote 2, p. 1.

⁴ Final Rpt, 1946, Ashford General Hospital. HD.

⁵ Annual Rpt, 1943, Letterman General Hospital. HD.

⁶ Ltr, Gen Somervell to CGs all SvCs and MDW, 17 Dec 43, sub: Hospitals designated for specialized treatment. SG: 323.7-5.

⁷ WD Cir 235, 12 Jun 44.

⁸ Annual Rpt, 1945, DeWitt General Hospital. HD.

⁹ Ibid.

¹⁰ See footnote 7 above.

Mayo General Hospital.¹¹ The vascular center at Mayo continued in operation until 17 October 1946¹² when it lost its designation. Lt. Col. Harris B. Shumacker, Jr., served as chief of section in this center during its entire period of operation.

ORGANIZATION

Although the vascular centers were briefly conducted as specialized surgical sections attached to the surgical service of the hospitals in which they were located, they soon became, for all practical purposes, independent units.

The organization was not precisely the same at all centers though it was always based on the principle that medical and surgical specialists should be in constant consultation with each other and should collaborate in the management of individual patients.

Organization at Ashford General Hospital. At Ashford General Hospital, at Torney, and at DeWitt during most of its period of operation, all patients with vascular disorders were assigned to the vascular surgical section. At these centers, when circumstances permitted, the following organizational setup was considered ideal:

A surgeon in charge of the center with wide experience in the field of vascular surgery. He performed most of the operations, was responsible for all administrative, medical, and surgical policies (in conformity with existing directives), and supervised all medical and surgical treatment.

An assistant surgeon, an experienced general surgeon, with fairly wide experience in vascular surgery. He supervised the center and carried out surgical procedures in the absence of the director.

Two medical officers with a thorough grounding, through training and experience, in the physiologic concepts of vascular diseases and injuries. They supervised or performed special tests, skin temperature and oscillometric studies, and diagnostic spinal punctures and lumbar sympathetic blocks (in collaboration with the chief anesthetist). At least 2 officers were necessary as it proved impossible for a single officer to appraise the vascular status of more than 4 patients per day.

A physiotherapist to give both diagnostic and therapeutic advice.

An officer to supervise reconditioning once definitive treatment was concluded.

A cardiologist to serve as consultant in appropriate cases and to advise on nonsurgical therapy. (While this officer was attached to the medical service, he was available for consultation at all times.)

A neurologist and neurosurgeon to serve as consultants; the former to attend weekly ward walks during which new patients were seen and the latter

¹¹ WD Cir 347, 25 Aug 44.

¹² Annual Rpt, 1946, Mayo General Hospital. HD.

to cooperate in the performance of sympathectomies. (These officers were attached to the neurologic service, but were available for consultation.)

Organization at Mayo General Hospital. The plan of operation at Mayo General Hospital differed from that at Ashford General Hospital in that the unit was divided into medical and surgical sections. The general understanding at this installation was that patients with vascular conditions requiring surgical treatment should be admitted directly to the surgical section. All other casualties were admitted to the medical section, from which, after the proper workup, they were transferred to the surgical section whenever surgery seemed indicated. Generally speaking, patients were admitted to the medical section if the diagnosis was trenchfoot, frostbite, thrombophlebitis, Raynaud's disease, peripheral edema, or vasospastic and obliterative arterial disease without ulceration. Patients were admitted directly to the surgical section if the diagnosis included arterial aneurysm, arteriovenous fistula, traumatic lesions of the blood vessels, gangrenous and other open lesions of vascular origin, varicose veins, hemangioma, or venous thrombosis. These policies, while carried out with reasonable consistency, were by no means inflexible. Patients with post-traumatic vasospastic disorders, for instance, might be admitted to the surgical section in some instances and to the medical section in others. The decision depended upon the particular clinical manifestations which the patient presented at the time of his admittance.

This plan was adopted at DeWitt General Hospital in May 1945 and was followed until the center was closed.¹³

Collaboration Among Services

No matter what the details of organization were in any particular center, the management of patients with vascular lesions was always a combined responsibility. The amount of work prevented collaboration in every case, but whenever it was to their best interests, patients were treated jointly by internists and surgeons. They were never regarded as the sole responsibility of one service or the other.

At all centers, collaboration with the department of roentgenology was excellent. The physical therapy and reconditioning department participated actively in the care of patients. Their personnel supervised corrective exercises and gave the special treatments required by patients with cold injuries and with trauma to the major arterial stems. When personnel of the physical therapy department was in short supply, as it frequently was, corrective gymnastic exercises were developed by the reconditioning section and were used, as far as possible, as substitutes for physical therapy.

In all centers, full use was made of the occupational therapy departments, partly for reconditioning purposes and partly to supply diversion during necessarily prolonged periods of hospitalization. Red Cross workers also

¹³ See footnote 8, p. 2.

participated in the programs at the vascular centers. At DeWitt General Hospital a special ward was set aside for patients who agreed to discontinue smoking as a phase of the therapy. Special privileges were granted to these patients and Red Cross workers were particularly cooperative in providing recreation.

Ward Rounds

Time was saved and efficiency increased by the coordinated ward rounds held weekly at each center. They were attended by all members of the medical and surgical staffs and by others concerned with the treatment of patients with vascular lesions. At these rounds new patients with problems of special interest or special difficulty were presented, the management of unusual cases discussed and agreed upon, and general policies were explained. Weekly progress notes on each case were also dictated at this time by the section chief. In addition to the ward walks, dry clinics were held at regular intervals.

PATIENT LOAD

Ashford General Hospital

The original allotment of beds for the vascular center at Ashford General Hospital was 50 out of a total bed capacity of 1,875; this was increased as the patient load increased, and at the height of military activity 600 beds were so allotted. Typical of the proportionate distribution of cases was the report made by a representative of the Office of The Surgeon General¹⁴ who inspected the center in September 1944. At that time, of the 241 patients in the vascular section of the hospital, 164 had trenchfoot, 33 had aneurysms or arteriovenous fistulas, 16 thrombophlebitis, 7 thromboangiitis obliterans, 5 Raynaud's disease, 3 frostbite, and 13 miscellaneous vascular conditions.

The heavy patient load carried by the Ashford General Hospital Vascular Center during 1944 and 1945 (Table 1), and the number of operations performed there during those years (Table 2), clearly indicate the wisdom and expediency of concentrating patients with vascular injuries in centers where they can receive highly specialized treatment. The statistics also provided evidence that concentration in these centers of the few available specialists is an economical use of personnel, for under any other setup their particular skills would be dissipated.

Percy Jones—Mayo General Hospitals

Because of the physical limitations of Percy Jones General Hospital, only 28 patients were admitted directly to its vascular section. Another 23 were transferred from other sections of the hospital; 78 were seen in consultation but not transferred. Thirty-eight operations were performed, including 23 sympathectomies and 4 excisions of arteriovenous fistulas.

¹⁴ Memo, Lt Col M. E. DeBakey, Chief Gen Surg Br, Surg Consultants Div for SG, 13 Sep 44, sub: Report of visit to Ashford General Hospital. HD: 730 (Ashford Gen Hosp).

TABLE 1. COMBINED DIAGNOSTIC ANALYSIS REPORT ASHFORD GENERAL HOSPITAL
VASCULAR CENTER

[1 January 1944—31 August 1945]

Diagnosis	Number of patients		
	1944	1945	Total
Arteriovenous fistula:			
Anterior tibial		11	11
Axillary	2	7	9
Brachial	6	11	17
Carotid artery and jugular vein	14	11	25
Cavernous sinus		2	2
Cirroid		2	2
Common iliac		2	2
External iliac	2	3	5
External carotid		3	3
Internal carotid		1	1
Femoral	33	40	73
Parietal scalp	1	1	2
Peroneal	3	6	9
Popliteal	17	27	44
Posterior tibial		10	10
Radial	1	1	2
Subclavian	12	14	26
Temporal	1	2	3
Tibial	14	13	27
Transverse scapular		1	1
Vertebral	1	2	3
Innominate	1		1
Vessels of foot	2		2
Multiple arteriovenous fistulas:			
Femoral, tibial, carotid (3)	1		1
Radial, right and left ulnar vessels (3)	1		1
Two tibial left, one tibial right (3)	1		1
Radial and Brachial (2)	1		1
Arterial Aneurysm:			
Anterior tibial		3	3
Axillary	1	8	9
Brachial	10	16	26
Carotid	2	2	4
Common iliac	2	1	3
External carotid		2	2
Femoral	5	8	13
Gluteal		1	1
Intracranial		1	1
Postauricular		1	1
Posterior tibial	4	8	12
Popliteal	4	6	10
Radial	4	4	8
Subclavian	8	3	11

TABLE 1. COMBINED DIAGNOSTIC ANALYSIS REPORT ASHFORD GENERAL HOSPITAL
VASCULAR CENTER—Continued
[1 January 1944—31 August 1945]

Diagnosis	Number of patients		
	1944	1945	Total
Arterial Aneurysm—Continued			
Ulnar		1	1
Thoracic aorta	1		1
Trenchfoot syndrome	348	634	982
High altitude frostbite	22	2	24
Thrombophlebitis, acute and chronic	156	186	342
Raynaud's disease	37	60	97
Thromboangiitis obliterans	66	98	164
with Raynaud's disease	2	1	3
Arteriosclerosis obliterans	13	19	32
Acrocyanotic syndrome	68	39	107
Secondary vasospasm	61	50	111
Varicose veins		15	15
Thrombosis, arterial	4	9	13
Thrombosis, venous	11	11	22
Postoperative ligation of major vessels	21	25	46
Postoperative arteriovenous fistula	6	3	9
Postoperative arterial aneurysm		2	2
Postoperative tonic vasomotor spasm		1	1
Venous incompetency		3	3
Constriction of arteries by scar		5	5
Dilatation of brachial artery		2	2
Causalgia	2	3	5
Embolie syndrome	1	2	3
Hemangioma	10	10	20
Angioma	2	2	4
Sudek's atrophy	9	2	11
Scalenus anticus syndrome	6	3	9
Periarteritis nodosa	2	5	7
Meralgia paraesthetica		1	1
Carotid body tumor	1	1	2
Rheumatoid disease with secondary vasospasm	3	3	6
Venous obstruction		1	1
Telangiectasia		1	1
Recurrent hematoma, left thigh		1	1
Traumatic gangrene of hand		1	1
Muscular pseudohypertrophic dystrophy		1	1
Veno-vitalium graft femoral artery	1	1	2
Fibrosis of calf muscles secondary to vascular insufficiency		1	1
Foreign body in ventricle	1	1	2
in myocardium	1		1
Lymphedema, chronic	5		5
Scleroderma, diffuse	1		1
Vasomotor imbalance	2	12	14

TABLE 1. COMBINED DIAGNOSTIC ANALYSIS REPORT ASHFORD GENERAL HOSPITAL
VASCULAR CENTER—Continued

[1 January 1944—31 August 1945]

Diagnosis	Number of patients		
	1944	1945	Total
Vascular reevaluation.....	152	71	223
No vascular disease.....	11	24	35
Total.....	1, 180	1, 547	2, 727

TABLE 2. COMBINED OPERATIVE ANALYSIS REPORT ASHFORD GENERAL HOSPITAL
VASCULAR CENTER

[1 January 1944—31 August 1945]

Procedure	Number of operations		
	1944	1945	Total
Excision of arteriovenous fistula:			
Femoral.....	22	35	57
Popliteal.....	18	20	38
with resection of fibula.....		2	2
Posterior tibial.....	15	22	37
with resection of fibula.....		8	8
Anterior tibial.....		6	6
with resection of fibula.....		2	2
Carotid artery and jugular vein.....	8	9	17
Subclavian, resection of clavicle.....	7	9	16
Brachial.....	4	10	14
Ulnar.....	3	2	5
Carotid.....	2	4	6
Peroneal.....	2	6	8
Axillary.....	2	8	10
with resection of clavicle.....		3	3
Iliac.....	1	5	6
Profunda femoris.....	1	4	5
Vertebral.....	1	4	5
Transverse cervical.....		2	2
Transverse scapular, with resection of clavicle.....		1	1
Superficial temporal.....		1	1
Cirroid of arm.....	1		1
Vessels of scalp.....	1	1	2
Vessels of foot.....	1	4	5
Vessels of hand.....	2		2
Excision of arterial aneurysm:			
Brachial.....	8	7	15
Subclavian.....	3	2	5

TABLE 2. COMBINED OPERATIVE ANALYSIS REPORT ASHFORD GENERAL HOSPITAL
VASCULAR CENTER—Continued

[1 January 1944—31 August 1945]

Procedure	Number of operations		
	1944	1945	Total
Excision of arterial aneurysm—Continued			
Femoral.....	6	3	9
Popliteal.....	1	1	2
Tibial.....	1	1	2
Axillary.....	1	3	4
Profunda femoris.....	1		1
Carotid.....	1	2	3
Radial.....		1	1
Cirsoid (1) hand and finger, (2) wrist.....		2	2
Ulnar.....		2	2
Endoaneurysmorrhaphy:			
Femoral.....	5	6	11
Brachial.....	5	4	9
Tibial.....	3	3	6
Radial.....	2	1	3
Axillary.....	2	2	4
Iliac.....	2	2	4
Popliteal.....	2	5	7
Profunda femoris.....	1		1
Posterior tibial.....		6	6
Ligation of artery:			
Common iliac.....	2		2
Femoral.....	1		1
Internal carotid.....		6	6
External carotid.....	8	3	11
Vertebral.....	2	2	4
Innominate.....	1	2	3
Superficial temporal.....	2	1	3
Transverse cervical.....		1	1
Occipital.....		1	1
Tibial.....		1	1
Ligation of saphenous veins.....	12	28	40
Amputation and debridement of toes and fingers.....	48	86	134
Amputation of feet.....	1	2	3
Excision of hemangioma.....	5	10	15
Scalenotomy.....	2		2
Excision of subclavian muscle.....	2		2
Excision of carotid body tumor.....	1		1
Exploration for lacerated vessels.....	2		2
Excision ingrown toenail.....	6		6
Dorsal laminectomy.....	1		1
Exploration subclavian artery, resection of clavicle.....		1	1
Suture femoral artery.....		1	1

TABLE 2. COMBINED OPERATIVE ANALYSIS REPORT ASHFORD GENERAL HOSPITAL
VASCULAR CENTER—Continued

[1 January 1944—31 August 1945]

Procedure	Number of operations		
	1944	1945	Total
Application tantalum clip to internal carotid artery and jugular vein.....		1	1
Venogram.....		1	1
Venous pressure determination.....		6	6
Biopsy of vein for thromboangiitis obliterans.....		1	1
Sympathetic block:			
Lumbar.....	320	77	397
Dorsal.....		34	34
Thoracic.....	12		12
Sympathectomy:			
Lumbar.....	196	168	364
Dorsal.....	6	35	41
Lumbodorsal.....		2	2
Lumbothoracic.....		1	1
Thoracodorsal.....		2	2
Lumbodorsal-thoracic.....		1	1
Total.....	765	695	1,460
Treatments:			
Mecholyl iontophoresis.....	1,627	565	2,192
Intravenous typhoid injections.....	110	155	265
Injection of varicose veins.....	32	63	95
Spinal anesthesia vasomotor tests.....	58	47	105
Alcohol vasomotor tests.....	3		3
Total.....	1,830	830	2,660

When this vascular center was transferred from Percy Jones General Hospital to Mayo General Hospital in September 1944, it was allotted 305 beds on the medical service and 195 beds on the surgical service. The allotment was increased or decreased according to the patient load but was in the neighborhood of 500 beds for the first 3 months the center was in operation. Bed capacity was increased to 724 on 6 January 1945, and to 800 on 26 January. Early in May 1945 the patient load decreased chiefly because of the diminution in the number of trenchfoot casualties, and on 20 May the bed capacity was again set at 500.

Between 15 September 1944 and 1 October 1945, 500 patients were admitted directly to the vascular surgical section at Mayo General Hospital, 365 operative procedures were carried out, and 540 patients from other parts of the

hospital were seen in consultation. The patient load on the medical vascular section was 68 in September 1944, 247 in December, and over 500 in January 1945. It remained at about this level until April. By the end of this month the medical service patient load had fallen to about 400, by the end of May it was about 250, and by the end of July only 125 were occupying beds. After this, the patient load was never over 100 on the medical service. In October orders were received that no more patients would be sent to the center and those remaining were gradually dispositioned, the center closing early in 1946.

Letterman—Torney—DeWitt General Hospitals

Thirty patients with vascular disorders requiring surgery were admitted to the vascular section of Letterman General Hospital during its period of operation. Of particular note were 221 patients with trenchfoot admitted to this center from Attu.¹⁵ While facilities were adequate at Letterman to handle the expected increase in patients with vascular disorders, the hospital was designated a debarkation hospital and directives were issued arresting the flow of patients requiring specialized care in order to make beds available for expected evacuees from overseas.¹⁶ At the time of deactivation, 23 December 1944, patients with vascular disorders were dispositioned to Torney General Hospital which had been designated a vascular center 17 December 1943.¹⁷

A 33-bed ward which constituted the facilities of the vascular center established at Torney General Hospital was almost completely filled from the day of its opening. The rapid increase in patient load made it imperative to secure further facilities and plans were made for more ward space as well as for an examining room, a constant-temperature room, and an office in one of the hospital cottages. Before they could be carried out, however, the center was transferred to DeWitt General Hospital, a newly constructed hospital where bed space was available to handle the great numbers of patients expected who would require this type of specialized care.

At DeWitt General Hospital the original allotment of the vascular center was 350 beds.¹⁸ Additional beds were assigned as the patient load increased and during the height of the trenchfoot load the allotment reached 500.¹⁹

PERSONNEL

When the vascular centers were first planned it was realized that their success would depend to a great extent on the capabilities of the medical personnel selected to staff them. Two factors were considered of primary importance: (1) assignment to the centers of the limited number of medical and surgical specialists of wide experience in the field of vascular injuries and

¹⁵ Annual Rpt, 1943, Letterman General Hospital. HD.

¹⁶ Smith, Clarence McK.: Hospitalization and Evacuation in the Zone of Interior. (Manuscript for an administration volume in this series.)

¹⁷ See footnote 6, p. 2.

¹⁸ Annual Rpt, 1944, DeWitt General Hospital. HD.

¹⁹ See footnote 8, p. 2.

diseases, and (2) retention of such selected personnel despite rotation policies. The latter consideration was adjudged of particular importance in a field as highly specialized as vascular surgery. It affected not only the medical officers but also the nurses, reconditioning personnel, physical therapists, medical detachment enlisted men, civilian ward attendants, technicians trained in the management of the constant-temperature rooms, and the WAC personnel. In spite of endeavors to prevent them, rotation and changes in personnel were frequent, and training programs to overcome the difficulties caused by this situation were steadily in operation.

When the vascular centers were first established, shortages in medical personnel were especially pronounced and especially serious. In an effort to overcome this shortage an attempt was made at DeWitt to utilize the services of ambulatory officer patients of the Medical Corps, but for a variety of reasons the policy was not satisfactory. Some of the patients were physically and emotionally exhausted from their combat experiences and were really unfit for anything but rest. Others felt that their stay in the hospital was limited and therefore had little interest in undertaking serious work. Still others were expecting separation from the service. Whatever the reason, the quality of work done by officer patients was frankly inferior and frequently had to be done over by the regular staff. The plan thus resulted in a loss of time and effort rather than a saving. It was quickly abandoned at DeWitt and was not put into effect at either of the other centers.

The large amount of paper work required in vascular cases, because of the many and repeated tests performed, made secretarial assistance of unusual importance. It was provided without too much difficulty at Ashford and Mayo General Hospitals but was a problem at DeWitt because of its inaccessible location. The situation was somewhat relieved shortly before the center was deactivated by the assignment of WAC personnel who served as medical clerks.

TRAINING PROGRAM

Because of the shortages of experienced personnel previously mentioned, the training of additional professional and nonprofessional personnel proved an important part of the function of the vascular centers.

The numbers of medical officers qualified for assignment to the vascular centers were augmented in several ways. Staff officers who were attached to these centers and who had had no previous experience in vascular injuries and diseases were rotated through the medical and surgical wards and eventually assigned to the operating room. This procedure enabled them to become familiar with methods of examination, diagnosis, and treatment. Medical officers with previous experience, but assigned to other stations, were sent to the centers where they were given intensive refresher courses. In addition, young medical school graduates who had completed their preliminary training at Carlisle Barracks, Pa., were sent to the centers for instruction. This training

program proved fruitful for not only were specialists augmented in number but also some developed such skill, dexterity, and judgment that they became capable of handling independently complicated vascular lesions and major vascular operations.

The training of nonprofessional personnel was a more informal, and practically continuous, process. Ward personnel were instructed in the specialized requirements of patients with various types of vascular injury. X-ray technicians, who had already received their basic training, were instructed in the techniques of arteriography and phlebography. Other technicians were trained in the operation of recording apparatus used in the constant-temperature, constant-humidity rooms, and in the performance of special tests.

PHYSICAL PLANT AND EQUIPMENT

Ashford General Hospital

Ashford General Hospital, White Sulphur Springs, W. Va., was housed in the Greenbrier Hotel. This hotel, one of the most beautiful in the world, was converted to its new purpose without the loss of any of its traditional beauty and charm. Patients in the vascular center located in this installation were therefore cared for in a structure that was physically adequate, well maintained, and extremely attractive. Furthermore, the natural surroundings and recreational facilities were of great value in the rehabilitation of patients after their definitive treatment had been accomplished. All the necessary facilities for a modern hospital were available including an operating pavilion, a roentgenologic department, clinical laboratories, a physical therapy section, a conditioning section, and photographic laboratories.

Initial difficulties in obtaining precision instruments and other equipment necessary for the management of patients with vascular injuries and diseases were overcome at the center by the loan of the personal instruments of one of the officers attached to the staff. Some of his equipment was used throughout the operation of the center because the Army was unable to supply certain special types of instruments needed.²⁰ Within a few months after the establishment of the center at this installation a constant-temperature, constant-humidity room was constructed and provided with elaborate electrical controls which permitted a range of temperature from 40° to 110° F., as well as varying degrees of humidity. This room was equipped with delicate precision instruments including Boulitte oscillometers of both the recording and the manual type, apparatus for skin surface temperature determinations, instruments for measuring skin resistance, and a plethysmograph. Special lights, simulating daylight, were provided for all examining rooms. A chemical laboratory was set up for blood volume studies and a ballistocardiograph installed for the study of the circulation in the presence of vascular lesions.

²⁰ In addition, great help was received from Dr. John M. Emmett and directors of the Chesapeake and Ohio Railroad Hospital located at Clifton Forge, Va., in the loan of instruments and linens, and the use of their operating rooms for sterilization.

Percy Jones—Mayo General Hospitals

When the vascular center at the Percy Jones General Hospital was first activated no special equipment was provided for the study of patients with vascular injuries and diseases. The difficulty was overcome by a member of the staff who loaned his own thermocouple and recording oscillogram. Oscillograms, thermocouples, cutaneous resistance apparatus, intermittent venous occlusion apparatus, a Sanders oscillating bed, and an ultraviolet light unit for intravenous fluorescein studies were requisitioned. Not all of these items were standard, however, and there was considerable delay in securing them. Since a controlled temperature room was not available, studies which are preferably done in a cool atmosphere were carried out in one of the air-conditioned operating rooms at times when it was not being utilized for surgical work.

Shortly after the transfer of the vascular center from Percy Jones to the Mayo General Hospital, the Mayo Institute for Medical Research, Cincinnati, loaned the center a thermocouple, an oscillogram, and a plethysmograph. An additional thermocouple and four oscillograms were eventually obtained through Army channels. A controlled temperature room which permitted the constant maintenance of temperatures at any desired level between 40° and 90° F. was completed in September 1945 and until that time a serviceable room was achieved by the use of an air-conditioning unit of the room type.

Letterman—Torney—DeWitt General Hospitals

According to reports from Letterman General Hospital in 1943, facilities and equipment were adequate for investigating and treating patients with vascular disorders.²¹ However, the hospital was becoming crowded by the flow of evacuees from overseas and since more beds were needed to handle an expected increase in numbers,²² the situation was solved by shifting the patients requiring specialized treatment to other hospitals.²³

When the vascular center at Torney General Hospital was first activated, a 33-bed ward constituted the facilities of its vascular center. The initial requisition for equipment included oscillograms, thermocouples, a dermometer, and an intermittent suction apparatus. Shortly before the center was transferred to DeWitt, two sets of equipment for intermittent suction and two portable potentiometers were received, though the thermocouples ordered were not. This equipment was transferred to DeWitt and there efforts were made by the staff to secure the items missing from the original requisition, as well as to secure additional equipment. These efforts were not entirely successful.

A Collins oscillogram was received in July 1945, but the Boultite and the Tycos recording oscillograms which had been requisitioned never materialized. A Van Slyke blood gas apparatus requisitioned in May 1944 arrived in July 1945. Other apparatus received after a considerable length of time

²¹ See footnote 5, p. 2.

²² Health-Monthly Progress Rpt, 28 Feb 43. HD: 720.-1.

²³ See footnote 16, p. 11.

included a photoelectric cell apparatus for determination of the circulation time, an ultraviolet dark lamp, and a Samuels pulsimeter. Supplies of fluorescein and Blakemore-Lord anastomosis ferrules were also late in arriving. A Henderson-Haldane gas analysis apparatus and a plethysmograph were requisitioned but never received. The two oscillating beds finally delivered were used to good advantage in surgical cases before and after operation. Special operating room equipment included pneumatic tourniquets, Bethune tourniquets threaded and padded with split rubber tubing for direct arterial compression, and a manometer for direct measurement of intravascular and intra-aneurysmal pressures.

When the vascular center was transferred from Torney to DeWitt General Hospital a request was made for a constant-temperature, constant-humidity room. When it was finally constructed and put into operation, alternating hot and cold currents of air, readily discernible to anyone in the room, were created every 6 minutes. Engineers corrected this condition in part by reducing the rate of air exchange.

In spite of the difficulties and delays encountered in securing special essential equipment for the vascular centers, and in spite of the fact that some apparatus requisitioned was never received, it was the consensus of the staffs that in no instance was the care of a patient seriously hampered nor the outcome of any procedure seriously influenced by these lacks. Shortages in operating room equipment were met by improvisations; those in diagnostic equipment by greater reliance upon clinical methods supplemented by judgment and experience.

It should be mentioned that the photographic laboratories established at each of the vascular centers proved valuable, since much of the progress of patients with vascular lesions can best be recorded pictorially.

RECORDS

Aside from the fact that careful and detailed records are essential in the management of patients with vascular lesions, it was considered particularly desirable to keep precise records at vascular centers because of the unique opportunity provided for the collection of mass data concerning vascular injuries. The compilation of these records was tedious and time-consuming and was sometimes accomplished with difficulty since medical personnel were overloaded with work and secretarial assistance was frequently inadequate.

Army medical history blanks proved unsuitable for the purposes of the vascular centers and special forms were developed.²⁴ They were found efficient and timesaving.

Much valuable material was collected from the photographic laboratories. This included black and white photographs of clinical conditions and pathologic lesions, colored photographs, transparencies for exhibit purposes, and drawings

²⁴ Vascular Surgery—Forms. HD: 730.

of operative procedures. These were used to great advantage in the training program.

CLINICAL RESEARCH

Delay in securing certain essential equipment prevented the carrying out of some of the clinical studies which had been planned. Blood-oxygen studies, for instance, outlined at DeWitt General Hospital were never initiated because of delay in the receipt of the chemicals required for use with the blood-oxygen apparatus. Despite plans, no plethysmographic studies were carried out at this center because the apparatus arrived after the patient load was so heavy that it was impossible to perform these time-consuming tests. It is regrettable that these and other studies could not be carried out because the amount of clinical material available in time of war can never be duplicated in a peacetime civilian practice nor, in time of peace, can available clinical material be concentrated and controlled as it can in time of war. In all the centers, however, clinical studies of immediate and future value were made on such subjects as trenchfoot and other cold injuries, thrombophlebitis, vasospastic states, ischemic paralyses, collateral circulation, the circulatory and other effects of aneurysms and arteriovenous fistulas, and the use of sympathectomy on various indications.

CHAPTER II

Evaluation of the Vascular Status in Traumatic and Nontraumatic Lesions of the Blood Vessels

*Ambrose H. Storck, M. D.**

The evaluation of the vascular status of patients with traumatic and nontraumatic lesions of the blood vessels encountered in World War II went considerably beyond mere diagnosis and differential diagnosis. It was useful, or essential, or both: (1) to determine the exact location and extent of a lesion or injury and to follow the progress of the disorder; (2) to determine vascular tone, patency of arteries and veins, functional capacity of blood supply, and adequacy of collateral circulation; (3) to establish need for surgical intervention, to select correct operative procedure and optimum time for operation and to assess the results of surgical therapy; (4) to establish therapeutic procedures other than surgical and to assess their results; (5) to determine the disposition of the patient whether for return to duty or for discharge, and, in the event of the latter, to establish degree of disability for pension purposes and to advise the patient regarding the resumption of his civilian occupation.

In medical installations in zones of combat and of communication the excessive workload of the medical personnel and the lack of special equipment made it mandatory to depend upon clinical methods alone for the study of casualties with injuries to the blood vessels. Clinical methods also constituted the major part of the investigation of the vascular status of casualties admitted to the three vascular centers in the Zone of Interior. The main reason for this reliance on clinical methods was that they yielded far more useful information than other types of investigation. There were, however, other reasons. In the beginning when the centers were first established, procurement of special facilities and diagnostic equipment was very slow, and the patient loads were heavy. In addition there were serious shortages in various categories of individuals, professional and technical, able to operate the special equipment as it became available. In fact it became necessary to institute a training program to overcome the lack of experience in management of vascular lesions and to develop teamwork among the ever-changing personnel.

The outstanding results achieved at all the vascular centers in spite of the initial shortages in equipment, supplies, and personnel, as well as of certain shortages which persisted to the end of the war, demonstrated two things clearly: (1) it is possible to provide safe and satisfactory care for patients with vascular lesions with limited facilities and equipment for special diagnosis; (2) given a nucleus of experienced personnel, it is possible to train personnel

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and to develop teamwork to meet all the essential requirements of a vascular center.

It should be mentioned, however, that the value of and need for certain special facilities—controlled temperature and humidity rooms and a minimum of certain other equipment—were never questioned. Each center was provided with a soundproof, specially insulated room built with 3 inches of cork block and with accoustically treated celotex on the ceiling, floor, and walls (Fig. 1). Apparatus with automatic thermostatic controls made it possible to regulate the temperature within these rooms at levels ranging from 40° to 110° Fahrenheit. Changes between the possible extremes of temperature could be effected within 45 minutes and changes of 10° or less, within 15 minutes. The air, which was filtered, was kept at a low humidity, usually 40 to 45 percent. Details of the provision of essential special diagnostic equipment have been given in Chapter I.



Figure 1. View of room with temperature and humidity controls used for examination and testing of patients with vascular injuries and diseases at vascular center of DeWitt General Hospital.

Consideration of the various objectives of the vascular evaluation and of their implications will make it clear why in most cases serial studies were carried out before and after operation and why in many cases testing was an essential part of the operative procedure. There were other reasons for the use of such studies including the possibility of error in the first test or tests; transient

psychic, environmental, and other influences which might affect the results; and possible improvement in, or worsening of, the patient's condition over a period of days, weeks, or months. As a rule, the diagnosis had been established before operation was undertaken, but in an occasional instance it proved impractical or impossible to localize the lesion accurately or to arrive at a diagnosis by indirect methods. In such cases surgical exploration was necessary for diagnostic as well as therapeutic purposes.

In this chapter the various clinical and laboratory techniques employed in the evaluation of the vascular status of patients admitted to the vascular centers at Ashford, Mayo, and DeWitt General Hospitals during World War II will be described. The techniques were for the most part the same at all three centers; any variations will be specified.¹ An occasional method will be described in greater detail in other chapters in this volume; however the indications for the various tests, the techniques, and the interpretation of results will be discussed completely, though in some instances briefly, in this chapter.

Clinical Material. The types of disorders encountered in the vascular centers were, with the exception of cold injuries, the same as those commonly encountered in the peacetime civilian population, but with a different distribution.

With comparatively few exceptions all patients were in the age group between 18 and 45. The younger patients far exceeded the older. An overwhelming majority were males, but as the war progressed, members of the Army Nurse Corps and of the Women's Army Corps were seen in increasing numbers with various noncombat-incurred vascular disorders.

The racial distribution of patients with vascular lesions was as varied as the racial makeup of the Army; however there were certain disproportions. Comparatively few Negroes were seen at any of the centers and at Ashford General Hospital, where a special study was made, a disproportionately large number of Caucasians with thromboangiitis obliterans were noted to be of the Jewish faith. Percentagewise these latter patients accounted for 35.8 percent of those with the disease.

Trenchfoot, immersion foot, and frostbite, especially high altitude frostbite, presented problems new to most medical officers. As a result, rapid formulation of diagnostic methods was necessary. Numerically, immersion foot and frostbite were not important, but trenchfoot by reason of the overwhelming number of cases was extremely important. On the other hand arteriosclerotic vascular disease, frequently observed in civilian practice, furnished few problems because of the youth of most of the military personnel.

Recording Methods. Standard data concerning vascular casualties (history, physical findings, and laboratory reports) were entered on the sheets regularly in use in Army hospitals. In most cases special and repeated tests proved necessary and the data thus secured were entered on special forms which had

¹ Standardized techniques which were employed without modification will not be described in detail.

been devised at the three vascular centers. These forms were by no means ideal but the heavy workload and the number of relatively or completely inexperienced persons who were recording the observations made shortcuts of this sort necessary. The use of these forms assured the uniform recording of pertinent data and also simplified the tasks of review and analysis of the records when lessening of the workload permitted these investigations. The special forms devised for patients with trenchfoot and other cold injuries proved invaluable when the centers were suddenly called upon to test and treat large numbers of casualties with these conditions.²

In cases exhibiting vascular lesions of particular interest, photographs, including color photographs, were employed to supplement the initial records as well as to show the intermediate status of the patient and the final results of treatment. Infrared photography was used to demonstrate collateral venous channels not visible by inspection. Photographs were taken at the operating table and specimens photographed according to the indications in special cases. These photographs were often supplemented or replaced by illustrations drawn by artists.

Both photographs and drawings were regarded as essential parts of the record. They were provided as often as circumstances permitted because physical appearances could thus be correlated with the results of various tests.

CLINICAL HISTORY

General Information

The special vascular history secured data which covered the patient's chief complaint, given in his own words; family history including any occurrence of vascular disease in his forebears; previous history including any occurrence of venereal disease, previous operations or injuries, possible exposure to excessive cold, incidents of phlebitis or migratory thrombophlebitis, and any isolated symptoms or manifestations of preexisting vascular disease; also his military history including assignments in the Zone of Interior and overseas with details of duties and experiences.

In addition, every patient with a vascular injury or nontraumatic vascular disorder was carefully questioned in order to secure a chronologic, factual, circumstantial account of its occurrence or development and to elicit symptoms and happenings which might have a possible relation to the vascular system. The taking of this history afforded an excellent opportunity to gain some insight into the patient's general attitude and characteristics. His own estimation of the disease or injury was frequently revealing, especially in regard to his evaluation of the related degrees of disability and functional limitation.

The patient was questioned concerning the use of tobacco in the form of cigarettes, cigars, pipe, chewing tobacco, and snuff, the amount used, and the

² Vascular Surgery—Forms. HD: 730.

duration of the habit. He was similarly questioned concerning the use of alcohol and drugs. His dietary habits were inquired into with special emphasis on those which might result in vitamin deficiency or general nutritional deficiency.

Specific Information

As far as was practical, data concerning the patient's present illness or injury were obtained in his own words, supplemented by such questioning as might be necessary in order to obtain the essential information concerning:

1. The time and place of injury or the place and date of the onset of symptoms.

2. The conditions or circumstances under which the injury was sustained or the symptoms first experienced. If the lesion was traumatic, a special note was made about the amount of the blood loss and whether or not infection had followed.

3. The methods and circumstances of evacuation were elicited including times and places, the manifestations en route, the findings so far as the patient knew them, previous treatment, and results obtained during previous hospitalizations for the present condition.

4. All symptoms experienced. Detailed questions were asked about those symptoms which might reflect abnormal vascular tone, vascular occlusion, or impaired vascular functional capacity. Details were also secured upon the location, onset, duration, and severity of special symptoms and signs, as well as on environmental conditions, activities, or other circumstances which relieved or aggravated them.

5. Specific data concerning the character, intensity, and chronicity of pain, as well as the circumstances under which it occurred, was aggravated, or relieved. The occurrence of rest pain or pain following exercise was noted. A distinction was made between pain in the small muscles of the foot and pain in the calf muscles; the experience at the vascular center of Mayo General Hospital showed that this distinction was important in thromboangiitis. Other symptoms and signs about which the patient was questioned if he did not himself supply the information included coldness or abnormal warmth of the hands and feet and other areas of the skin, excessive dryness of the skin or excessive sweating, abnormal fatigability, numbness, tingling, burning, anesthesia, hypesthesia, hyperesthesia, alternating warmth and coldness, cold or heat sensitivity as distinguished from coldness or abnormal warmth, pallor, rubor, cyanosis, edema, stiffness, vesicle-formation, desquamation, ulceration, gangrene, loss of nails, varicosities, and symptomatic evidence of associated nerve injuries.

6. Injuries or lesions occurring in parts of the body other than the extremities. Here a different line of questioning was adopted. If an intracranial vascular lesion was suspected, such as an intracranial aneurysm or a carotid-cavernous sinus arteriovenous fistula, inquiries were made concerning

such symptoms as headache, vertigo, tinnitus, syncope, periods of unconsciousness, convulsions, motor or sensory abnormalities, nausea, and vomiting. If an intrathoracic vascular lesion was suspected, the questioning was directed to such symptoms as cough, expectoration, chest pain, voice changes, dysphagia, and dyspnea. Myocardial changes, cardiac decompensation, and other cardiac alterations were regarded as possible associated states in special types of injuries and lesions and the questioning in these cases was directed to the occurrence of palpitation, dyspnea, orthopnea, cough, and other symptoms and signs indicative of cardiac involvement.

Emotional Status. Emotional and psychologic factors played a more important role in the military casualty than in the civilian patient. They had to be taken into consideration in obtaining the clinical history and interpreting certain subjective reactions to physical examination such as pain, tenderness, and claudication. Phlegmatic individuals, just as in civilian life, tended to minimize their symptoms, while excitable or poorly adjusted patients tended to exaggerate theirs. Intentional or unintentional distortion or inaccurate description of symptoms was not uncommon.

Emotional factors connected with life in the Army were especially likely to assume importance in the vasospastic group of patients. The most important of these factors were regimentation, separation from family, fear, including fear of return to duty, which was especially prominent in enlisted men as compared with officers, and the desire to be compensated for injuries. Judicious questioning was necessary to elicit and evaluate these various factors. It was also necessary to observe the patient and to consider him from the standpoint of general appearance, attitude, off-guard behavior, and habits. These indirect observations were often of great importance in the evaluation of the emotional and psychologic components of the vascular status. In some instances neuropsychiatric consultation was necessary for complete evaluation and disposition.

Repetition of Questioning. The more or less sudden changes which often occurred in patients with vascular lesions as a result of physical and other environmental influences or of emotional reactions, or as the result of rapid regression or progression of the vascular lesion, made it necessary to question the patient frequently concerning the status of his symptoms, the possible appearance of new symptoms, and his own evaluation of his condition. Repeated questioning was as necessary as repetition of objective studies. It was observed, for example, that patients with trenchfoot who had complained of great pain, had actually manifested excessive sweating and color changes in the affected part, and had gladly accepted litter transportation, often, shortly after their arrival in the Zone of Interior, experienced rapid reduction of pain and showed great improvement in other subjective manifestations. Improvement was always notable when these patients learned that it was not Army policy to return patients with trenchfoot to duty. Failure to appreciate the likelihood of these rapid changes and to look for them in patients with trench-

foot and other vascular lesions could conceivably have resulted in unnecessarily radical, actually harmful, therapeutic measures.

PHYSICAL EXAMINATION

General Considerations

Ordinary methods of physical examination were combined with special methods which required no complicated apparatus or equipment. In the course of routine physical examination search was made for indications of injury to, or occlusion of, blood vessels, abnormal arteriovenous communications, abnormal vascular tone, impaired functional capacity, and trophic or other changes. Special tests were then carried out according to the indications of the particular case. Inspection, palpation, percussion, auscultation, and mensuration were found to be essential phases of all such examinations. The vascular findings were described in as much detail as time permitted and were also indicated on special diagrams.

The initial physical examination was usually performed in ordinary environmental circumstances, in the ward, the patient's room, or the standard examining room. Subsequent examinations were conducted in a room in which the temperature and humidity could be controlled. The temperature was usually kept at 68° to 78° F. and the humidity at 40 percent. All examinations were carried out with the patients entirely, or almost entirely, disrobed.

The possible effects of environmental temperature and humidity at the initial (routine) physical examination, and of psychic and emotional influences at all examinations, had to be taken into consideration in the interpretation and evaluation of all findings. Another reason for repetition of physical examinations was the possibility of rapid regression or progression of physical manifestations of vascular lesions. This was particularly true in such types of lesions as pulsating hematomas and aneurysms which sometimes increased rapidly in size and consequently produced nerve damage and circulatory impairment distal to the site of the lesion.

Height and weight were recorded at the original examination, and weight was determined as often as seemed indicated thereafter provided the patient was not weighed at regular (usually weekly) intervals.

Vital Signs

In the absence of infection the oral temperature supplied no special information in patients with vascular injuries and lesions, but its observation formed part of every physical examination. Pulse rate was determined in an artery presumed free of injury or disease. Respiratory rate was recorded routinely but seldom furnished information of much significance.

Blood pressure was also taken in some artery not directly involved in the vascular injury or lesion and regarded as least affected by it. Determination

of comparative pressures proved a useful method of examination in vasospastic and obliterative vascular lesions, as well as in arteriovenous fistulas, arterial aneurysms, and arterial occlusions which had been produced surgically. When the extremities were fat or edematous determination of blood pressure was often unsatisfactory and unreliable. Better results were secured in such cases when a special wide cuff was substituted for the usual sphygmomanometer cuff. Serial determinations of the blood pressure were important as findings might alter from time to time, sometimes from day to day. It was noted that after the closure of large arteriovenous fistulas the blood pressure was sometimes considerably elevated, even to hypertensive levels. Blood pressure determinations after temporary obliteration of the blood flow through an arteriovenous fistula will be discussed later in this chapter.

Inspection

General inspection of the entire body was followed by detailed inspection of special parts, particularly the extremities. Comparative observations were always made on both extremities.

Inspection was directed to the following points:

1. General development and nutritional status of the body.
2. The facies, particularly for the presence of exophthalmos.
3. The poise, attitude, manner of speech, and general behavior.
4. The gait, whether normal, limping, asymmetrical, or of the heel type, and whether there was weight-bearing on the lateral edges of the feet.
5. The respirations, whether normal, dyspneic, or orthopneic.
6. The general coloring, with special reference to pallor, cyanosis, or mottling.
7. The distribution of hair on the toes, feet, legs, fingers, hands, and forearms.
8. The muscular status, with special reference to atrophy or hypertrophy.
9. The skin, with special reference to vesiculation; pigmentation of abnormal degree or distribution; trophic changes, including thickening (hypertrophy) or thinning (atrophy); callus-formation; fibrosis; scleroderma; desquamation, with special reference to the degree and distribution.
10. The presence of amputations or contractures of the digits or of portions of the extremities.
11. The presence of healed or unhealed wounds, and of scars.
12. The presence of ulceration of the digits or of other areas.
13. The presence of infection and its differentiation into pyogenic and mycotic types.
14. The presence of gangrene (moist, infected, or dry) and of lines of demarcation and separation.
15. The condition of the nails and finger tips, with special reference to ridge-formation, rolling, cracking, cornification, and clubbing.

16. The presence of masses and their differentiation into pulsating and nonpulsating types.

17. The presence of other abnormal pulsations.

18. The status of the blood vessels with special reference to visibly tortuous arteries, collateral venous channels, and varicosities.

19. Abnormal sweating or abnormal dryness of the skin, its degree, distribution, symmetry or asymmetry, and constancy or intermittency. Special sweating tests were carried out as indicated.

20. Edema, with special reference to location, degree, extent, and character (whether pitting or nonpitting).

21. Color changes in the affected extremity.

Careful observation of changes of color in the extremities was of great importance in vasospastic and obliterative arterial diseases and was occasionally of value in the estimation of circulatory impairment in patients in whom there had been loss of continuity of blood flow in the main arterial stems as the result of trauma or operation. The examination called for no refined methods of judging color but merely for careful observation of the involved extremity and comparison with the opposite extremity. Good daylight was essential and the preferable environmental temperature 76° Fahrenheit. Observations were made with the patient recumbent and with the limb to be investigated placed successively in the horizontal, dependent, and elevated positions. Note was made of the extent and degree of cyanosis, rubor, pallor, and livedo reticularis, and of the changes of color occasioned by return of the extremity to the horizontal position after either elevation or dependency.

In addition to the observations already listed, two possible clinical entities were looked for: (a) phlebitis, with special reference to the location, extent, degree of clotting, and activity or inactivity of the involved veins, and (b) migratory phlebitis, with special reference to the distribution and character of the lesion, the presence of local pigmentation and fibrosis, and the appearance of areas of fresh venous inflammation.

Palpation

Palpation was an indispensable method of examination in patients with penetrating wounds. It was done with great care in the vicinity of the wounds of entry and exit and in the area between them in order to detect possible thrills and pulsations. When a penetrating wound had been produced by a bullet, shell fragment, or other foreign body which had not made its exit, the area between the wound of entry and the site of roentgenologic visualization of the retained foreign body was carefully palpated. When there were multiple and widely distributed penetrating wounds, it was the usual practice to palpate the entire body. Areas contiguous to fractures were also palpated with special care.

Certain data secured by palpation were in confirmation of, or in extension of, data already obtained by inspection; these particularly concerned edema,

abnormal dryness or excessive sweating, trophic changes in the skin, and the presence of masses and abnormal pulsations. Other data obtained by palpation included:

1. Surface temperature, with particular reference to grossly detectable deviations from the normal, including coolness or coldness, localized hot spots, and diffusely increased heat.

2. Variations in sensation, including anesthesia, hypesthesia, hyperesthesia, and tenderness. Tenderness in the ball of the foot was always looked for in patients with trenchfoot, and tenderness in the calf was always investigated in patients with suspected venous thrombosis.

3. Fixation of the skin as the result of recent or old traumatic or inflammatory processes.

4. The status of the musculature, with special reference to spasm and atrophy. When the scalenus anticus syndrome was known or suspected to be present, tenderness or spasm of the shoulder girdle was investigated.

5. Thrills, which indicated the presence of arteriovenous fistulas and arterial aneurysms.

6. Venous thrombosis, which might be present in phlebitis involving the superficial veins.

7. Varicosities not demonstrable on inspection, particularly in obese patients or in patients with edema and cutaneous and subcutaneous fibrosis.

8. Atheromatous changes in the peripheral arteries.

9. Anatomic vascular anomalies, including absence and/or displacement of arteries from their normal location as the result of aberrant development. In a fairly large number of apparently normal persons dorsalis pedis pulse could not be palpated at all, while in others it was found in anomalous locations.

In addition to generalized palpation of the whole body or of certain regions, main arteries of both the upper and lower extremities (dorsalis pedis, posterior tibial, popliteal, femoral, radial, brachial, and axillary) were palpated to determine the degree of elasticity, the presence of arteriosclerosis, tortuosity, thrills, and the volume or amplitude of pulsation. Special attention was directed, when indicated, to other arteries such as the temporal artery.

If the radial pulse was palpated with the arm in hyperabduction, it was borne in mind that compression of the subclavian artery may occur in some normal persons when the arm is in this position, with resulting diminution or obliteration of the radial pulse. It was also borne in mind that palpation of the radial pulse during forced respiration against resistance may likewise reduce or obliterate it and that a radial pulse may be absent as the result of a developmental anomaly.

The degree of pulsation was recorded either as good, moderate, faint, or absent, or on a scale of 0 to 4, 0 indicating absent and 4 normal. Care was taken to indicate whether the record concerned the pulse on the right or the left side; both were always tested.

Percussion

Percussion was employed routinely to define the borders of the heart, particularly for the demonstration of cardiac enlargement in patients with arteriovenous fistulas. It was probably the least useful of the various methods of physical examination employed in patients with vascular injury or disease.

Auscultation

Auscultation was carried out, as under ordinary circumstances, to detect cardiac murmurs and variations in the cardiac rate and rhythm. These data were of special importance in patients with arteriovenous fistulas. This method was also useful in searching for bruits in areas in which thrills had been palpated. It was done routinely:

1. In patients with multiple penetrating wounds. In such cases it was carried out, like palpation, over the entire body, especially along the course of major arteries in search for vascular lesions manifested by the presence of a bruit.
2. In the vicinity of wounds of entry and exit and in the area between them, or in the area between a wound of entry and the site of roentgenologic visualization of a retained foreign body.
3. In regions contiguous to fractures, in search for bruits which would indicate associated vascular lesions.

The ordinary stethoscope was used at all the vascular centers. At the DeWitt General Hospital there was used, in addition, the double stethoscope known as the symbolophone. This instrument permitted auscultation at two separated points simultaneously.

Mensuration

Mensuration which demonstrated possible differences in the circumference of the extremities at various levels was particularly useful in patients with thrombophlebitis, arteriovenous fistulas, or arterial aneurysms. Comparative measurements were always made on the contralateral limb and the method was always used serially.

The practice differed somewhat at the three centers. At Ashford General Hospital five measurements in the lower extremity were taken, at the midpoint of the foot, the ankle, 18 cm. below the midpatella, at the level of the knee, and 18 cm. above the midpatella. In the upper extremity five measurements were also taken, at the midpalm, the wrist, 10 cm. below the olecranon process, at the cubital level, and 10 cm. above the olecranon process. These points were marked on the extremities before mensuration was begun.

At the Mayo General Hospital Vascular Center the procedure was as follows: The thigh was measured at a point 5 to 6 inches above the upper border of the patella; the leg 4 to 5 inches from the lower border of the patella; and the lower leg 1.5 inches from the upper border of the internal malleolus. All measurements were made first with the knee flexed and then with the extremity lifted from the bed. The lower edge of the tape measure was placed slightly

above the guide mark and the extremity encircled at exactly the same level all the way around.

Tests for Nerve and Muscle Status

The frequent association of other injuries with vascular injuries required examination of the affected parts for bone, nerve, and muscle injuries which had practically always been detected before the patients reached the vascular centers but the sequelae of which were not always clear. Demonstration of the sequelae of nerve injuries required testing for normal and abnormal reflexes, areas of hypesthesia, hyperesthesia, and anesthesia, tenderness in the balls of the feet, and atrophy of the muscles of the feet and hands. Observations based upon active and passive movements and upon manipulation of the extremities or, in some instances, of the neck, furnished information about the limitation of motion caused by muscle weakness resulting from nerve injury, circulatory impairment, disuse, stiffness or ankylosis of joints, and pain resulting from movement but attributable to other causes.

The functional limitations manifested by the presence of claudication will be discussed later in this chapter.

Ophthalmoscopy

The use of the ophthalmoscope was a routine part of the general examination in patients in the upper age groups and in patients of all age groups with intracranial aneurysms or with arteriovenous communications between the internal carotid artery and the cavernous sinus. Examination of the retinal vessels by this means often yielded information of considerable value.

CLINICAL LABORATORY TESTS

The majority of clinical laboratory tests were found to be of little or no help in evaluating the status of patients with either organic or vasospastic obliterative vascular diseases. This statement holds for the blood coagulation time, the bleeding time, the sedimentation rate, and hematocrit determinations. Prothrombin time determinations, while they were of no help in evaluation of the vascular status, were essential in patients receiving dicumarol (bishydroxycoumarin) therapy. Coagulation time determinations did not reflect the anti-coagulant effects of dicumarol as they did in patients receiving heparin.

Blood chemistry determinations seldom furnished significant data in the patients seen at the vascular centers. This might have been expected as most of them were young and healthy adults in whom abnormalities of the blood chemistry were unlikely to be present.

The heparin tolerance test suggested by De Takats³ was used in a limited number of cases at the vascular center of DeWitt General Hospital but did not yield uniformly dependable results and was considered of little clinical value.

³ De Takats, G.: Heparin tolerance; test of clotting mechanism. *Surg., Gynec. & Obst.* 77: 31-39, Jul 1943.

SPECIAL TESTS WITHOUT INSTRUMENTS

To supplement the data obtained by ordinary methods of physical examination, certain maneuvers and tests which did not require special diagnostic equipment were employed. One such group of tests consisted of Allen's blanching test, Samuels' plantar test, the exercise test for the upper extremities, the ischemic pain test, and Homans' dorsiflexion test.

Blanching Test (Allen)

Allen's test, which was used when one of the main pulses in the wrist was not easily palpable, was performed by elevating the patient's hand above the level of the head until blanching appeared. The radial artery was then compressed and the hand brought down. Persistency of blanching in the dependent position was taken to mean occlusion of the ulnar artery, while prompt return of color was taken to mean that the ulnar artery was patent. The test was sometimes repeated after a 1-percent procaine solution had been injected into the stellate ganglion in order to eliminate a possible vasospastic element.

Plantar Test (Samuels)

Samuels' plantar test, which is an exercise test for the lower extremities, was performed with the patient recumbent and the lower extremities elevated at an angle of 45 degrees or more. The color of the soles was noted before and after the limbs had been raised. The patient flexed and extended the feet with the ankle as a pivot for 2 to 3 minutes. If the arterial supply to the feet was adequate, the plantar surfaces kept their normal pinkish tinge. In the presence of arterial occlusion of even minimal degree a decided pallor became apparent usually within 2 to 3 minutes, though it did not necessarily involve the whole sole; in some instances pallor was confined to the toes or the forepart of the foot. The Samuels exercise test yielded positive results in a number of patients in whom positional color changes could not otherwise be demonstrated. It was the general experience that the pallor produced by elevation of the extremity in thromboangiitis and in surgical arterial occlusion was almost always accentuated when this test was employed. The experience at Mayo General Hospital, where the test was widely used, was that results were invariably negative in Raynaud's disease and in thrombophlebitis.

Exercise Test for the Upper Extremity

The exercise test employed for the upper extremities was the counterpart of the Samuels' plantar test for the lower extremities. The patient elevated his hands with palms directed toward the observer and flexed and extended his fingers for 2 minutes. Blanching occurred in areas affected by arterial obstruction of any origin, while areas to which the blood supply was normal kept their normal pinkish tinge. When stellate ganglionectomy was contemplated, this test, following injection of the stellate ganglion with 1-percent procaine solution, furnished some evidence of the results to be anticipated from the operation.

Ischemic Pain Test (Schechter and Ragan)

The ischemic pain test for diagnostic use in peripheral vascular disease was devised by Capt. Adolph A. Schechter and Maj. Charles A. Ragan⁴ in the Mediterranean Theater of Operations, when trenchfoot had become a serious problem there. With the patient recumbent, the cuff of a sphygmomanometer was placed around the leg just above the knee and the pressure within it elevated enough to obliterate the gross arterial flow (usually 220 mm. of mercury). Occlusion of the blood flow was continued for a maximal period of 5 minutes during which time the patient described any unusual sensation in the limb. After a 5-minute rest period the arterial supply was again occluded for a maximal period of 5 minutes and this time the patient flexed and extended the foot once every 3 seconds. In this period he again described any unusual sensation. The results of the test were considered positive if the patient complained of pain in or around the base of the toes in the region of the metatarsal or longitudinal arch of the foot as distinguished from pain on the dorsum of the foot at the level of the malleoli and along the anterior surface of the lower leg which is the pain caused by exercise.

The results of this test were too variable to permit much reliance to be placed upon it in the study of patients with vascular lesions. The time of onset and the intensity of the pain after occlusion of the blood supply could not be correlated definitely with other diagnostic criteria or with the actual progress of patients with trenchfoot. Moreover, a control study of normal individuals revealed that minor sensations which they described while the test was in progress could be interpreted as similar to, or identical with, those experienced by patients with trenchfoot.

Another consideration which made the ischemic pain test of questionable value was that its results depended upon the patient's subjective interpretation of his experience. Prolonged observation of patients with trenchfoot made it clear that a fair evaluation of their subjective complaints was most difficult. With continuous hospitalization even slight complaints tended to become intensified in their minds, and only men of strong character and high morale were likely to resist the subconscious temptation to enlarge on their troubles when they were given the opportunity offered by this test.

Dorsiflexion Test (Homans)

Homans' dorsiflexion test, which is widely used in civilian practice in the diagnosis of thrombosis of the deep veins of the leg and foot, was also widely used in the vascular centers. The results were regarded as positive if pain occurred in the calf muscles when the foot was placed in dorsiflexion. Compression of the plantar portion of the foot was also practiced to determine whether pain would be produced in it by this maneuver. In military practice this test was often found to yield positive results in the absence of thrombosis

⁴ Ragan, C., and Schechter, A. E.: Clinical observations on early trenchfoot. *M. Bull. Mediterranean Theat. Op.* 3: 264-266, Jun 1945.

if there had been trauma to the leg, particularly to the calf muscles or to the Achilles tendon.

Other Tests

Occlusion of the direct flow of blood between the artery and vein involved in an arteriovenous fistula, by pressure at or proximal to the fistula, gave rise to two phenomena which were elicited as part of the special vascular examination. Branham's (Nicoladoni's) sign is a temporary reduction in the pulse rate following occlusion. It was present in all arteriovenous fistulas observed at the vascular centers except for a few in which the opening between the artery and vein was extremely small. Studies at the vascular center of Ashford General Hospital showed that this sign did not occur when atropine in appropriate dosages was administered intravenously before digital compression was applied.

Gunderman's sign is a transient rise in the diastolic blood pressure following digital compression of the artery. The systolic blood pressure is either unaltered or only slightly elevated. This sign was present in all the arteriovenous fistulas observed at the vascular centers unless the opening between the artery and the vein was unusually small.

TESTS OF THE COLLATERAL CIRCULATION

The extent and adequacy of the collateral circulation was a matter of great significance in the diagnosis, management, and prognosis of vascular lesions. It was determined by a variety of tests and observations including Delbet's test, observation of the effect of prolonged compression of the artery involved in an aneurysm or arteriovenous fistula, reactive hyperemia tests, the claudication time test, and the reflex vasodilatation test. A number of other clinical tests were introduced at the vascular centers but proved unreliable and were not widely employed. Additional studies of the collateral circulation were made by special methods such as arteriography and determinations of intravascular pressure during operation. These methods will be described later in this chapter under appropriate headings.

The safety of an operative procedure, predicated on preoperative studies which indicated the existence of an adequate collateral circulation, was based on the premise that no important collateral vessels would be sacrificed during operation. If this condition was not met, disaster was likely to follow.

Delbet's Sign

Delbet's sign⁵ is the clinical evidence of adequate circulation distal to an aneurysm, even in the absence of distal arterial pulsations in the part. When this sign was present the collateral circulation could be assumed to be good. Its presence was of particular value in aneurysms. It was repeatedly observed, even when the arterial pulses had disappeared distal to the lesion, that if good circulation had been maintained in the limb, ligation of a major artery was unlikely to be followed by any ischemic difficulties.

⁵ Delbet, P.: Extirpation d'un anévrisme poplité; guérison. Bull. et mém. Soc. de chir. de Paris 35: 865-870, 1909.

In some cases observed at the vascular centers Delbet's sign was not present originally but appeared after sympathetic block or sympathectomy had been performed. It was often present in high subcutaneous ruptured aneurysms in which other tests for the collateral circulation could not be satisfactorily performed because of the great size of the aneurysm or because tenderness and pain on pressure precluded compression of the artery.

Occlusive Compression Test

Another useful test of the adequacy of the collateral circulation was observation of the color and warmth of the hand or foot during prolonged occlusive compression of an aneurysm. If the part remained warm and of good color, good collateral circulation could be assumed. The position of the extremity during the period of occlusion was important in the evaluation of the circulatory status. It was considered necessary to assay the circulatory status of the hand or foot in positions other than the horizontal one. Marked pallor has been found to occur when the extremity was elevated, although both color and warmth would remain normal in the horizontal position during periods of compression lasting as long as 30 minutes.

When ligation of the internal carotid artery had to be performed for cavernous sinus-internal carotid fistulas or similar lesions, it was customary to determine by means of a mechanical compressor (Fig. 2) whether the patient could tolerate compression of the carotid vessels, eventually for as long as 30 minutes, without symptoms. One of the chief drawbacks to the satisfactory performance of this test was the difficulty of maintaining precise and complete compression of an aneurysmal lesion over a prolonged period of time. With mechanical compressors it is often impossible to maintain exact occlusion of



Figure 2. Mechanical compressor for carotid artery.

the desired portion of the artery for a long period and with digital compression the fingers soon become exhausted.

Claudication Time Test

The distance that a patient with peripheral vascular disease was able to walk before the onset of annoying or incapacitating claudication proved a practical criterion of the competency of the circulation. This very simple test could be employed not only as an index of the patient's functional vascular capacity but also as a means of weighing the possible effectiveness of various therapeutic regimens including general measures, drug therapy, sympathetic block, and surgical procedures performed directly on the blood vessels. The test also proved useful after treatment, partly to determine results in the individual patient and partly for the group evaluation of various methods of management. By this means, for instance, it was possible to weigh the relative merits of quadruple ligation and excision in arteriovenous fistulas against those of restorative procedures of one kind or another.

In patients who suffered from claudication, sympathetic block with procaine hydrochloride was a useful and dependable means of determining before operation the improvement to be expected in this symptom from sympathectomy. The effect of reflex dilatation on the claudication time was also studied as an index to the element of vasospasm present and the expected results of sympathectomy.

Reactive Hyperemia Test

The combination of observation of Delbet's sign, prolonged occlusive compression of the blood supply, and the reactive hyperemia test proved a generally safe and satisfactory method of determining the adequacy of the blood supply of the part before operation. The reactive hyperemia test, which was introduced by Moschcowitz⁶ in 1907 to determine the safe level for amputation in gangrene of the extremities, was proposed as a method of estimating the efficiency of the collateral circulation by Matas⁷ in 1910 and has been widely used for this purpose ever since. In the vascular centers it proved particularly useful in instances of arterial aneurysms and arteriovenous fistulas in which surgical correction was contemplated.

In the performance of the test two observers always participated to be certain that the blood flow through the aneurysm or fistula had been successfully checked and to facilitate observations on color changes in the extremity.

The reactive hyperemia test was performed as follows: With the patient recumbent, the limb to be tested was elevated after which as much blood as possible was drained out of it. If the lesion was in the lower extremity, this was accomplished by applying digital pressure on the dorsal and plantar sur-

⁶ Moschcowitz, L.: Die Diagnose des Arterienverschlusses bei Gangraena pedis. Mitt. a. d. Grenzgeb. d. Med. u. Chir. 17: 216-228, 1907.

⁷ Matas, R.: Some of the problems related to the surgery of the vascular system; testing the efficiency of the collateral circulation as a preliminary to the occlusion of the great surgical arteries. Tr. Am. S. A. 28: 4-54, 1910; also in Ann. Surg. 53: 1-43, Jan 1911.

faces backward toward the heel and up toward the ankle. If the lesion was in the upper extremity, the hand could be thoroughly blanched by asking the patient to make a tight fist, or by milking the blood from the fingers and hand by the same procedure employed in the foot. The milking maneuver was continued until adequate blanching had been obtained.

A blood pressure cuff, which had previously been applied about the limb distal to the aneurysm or fistula, was then quickly inflated to a pressure of 200 to 220 mm. of mercury and complete interruption of the arterial inflow below this level achieved. The hand or foot, which by now was extremely pale, was lowered to a comfortable horizontal position. Before the test the most distal point at which digital compression of the artery completely stilled the aneurysm or fistula had been determined. This was indicated by absence of pulsation, thrill, and bruit. Four minutes after inflation of the blood pressure cuff, digital pressure was applied to this predetermined area and was maintained for 3 minutes during which the absence of pulsation and thrill was checked by palpation and the absence of bruit by auscultation. One minute after digital pressure had been applied (that is, 5 minutes after occlusive pressure had been produced by means of blood pressure cuff), the cuff was suddenly deflated and the rapidity, completeness, and intensity of the resulting flush were observed and recorded in seconds. The time interval which elapsed before hyperemia began in the most distal portion of the extremity, that is in the digits which it reached last, was recorded and the number of seconds which elapsed before it became complete in extent and in intensity was also recorded. After digital pressure was released, it was noted whether any further improvement occurred in the completeness or intensity of the hyperemia. If full and complete hyperemia occurred in less than 2 minutes, the collateral circulation was regarded as adequate.

The basal conditions under which the reactive hyperemia test was performed, as well as the precise technique, were matters of considerable importance. Reactive hyperemia was always more pronounced when the limb to be tested was in a state of vasodilatation rather than of vasoconstriction. In the absence of sympathetic denervation, limbs which were the site of aneurysms or arteriovenous fistulas were, like normal limbs, capable of a wide variation in vascular tonus. On the other hand, in deciding at the vascular centers whether the test should be performed under conditions conducive to vasodilatation or vasoconstriction, it was concluded that the initial test should be performed in circumstances which would induce neither vasodilatation nor vasoconstriction, for the practical reasons that the patient was destined to live in an ordinary environment after the test and that constant maintenance of vasodilatation could not be assured unless sympathectomy was performed.

Although Matas had determined that the reactive hyperemia test could be carried out with a blood pressure cuff, he believed that an Esmarch bandage was preferable because it brought about a more complete deprivation of blood and therefore a more intense reaction. In the vascular centers, however,

compression by the Esmarch bandage was reserved for those unusual cases in which adequate blanching of the limb could not otherwise be achieved, and even in these instances it was used only to milk the blood out of the limb; obstruction of the blood flow was maintained by means of the blood pressure cuff.

Digital rather than mechanical compression of the artery was preferred because more accurate occlusion could be achieved with less hazard of compressing adjacent or collateral vessels at the same time. Much emphasis was placed upon complete compression of the lesion. If this was not achieved and some blood still flowed through the compressed vessels, faulty deductions concerning the efficacy of the collateral circulation were likely to be made with disastrous consequences.

The site of compression of the artery was selected with great care since the most distal point at which digital occlusion produced cessation of pulsation, thrill, and bruit was taken to represent that portion of the artery which opened into the aneurysmal sac or communicated with the vein or sac in instances of arteriovenous fistulas. This was therefore the point at which, unless a reparative procedure could be performed, it would be necessary to ligate the artery.

Compression of the artery at some point proximal to the optimum point, though it might bring about cessation of pulsation, thrill, and bruit, could give rise to misleading conclusions. On the one hand, it might occlude the blood flow through collateral vessels which would be preserved if operative ligation proved necessary; the test would therefore demonstrate less adequate collateral circulation than actually existed. On the other hand, compression proximal to the aneurysm might leave open collateral channels which it might be necessary to sacrifice at operation; the test would therefore suggest that the collateral circulation was better than was actually the case. In one instance the misinterpretation apparently arose chiefly from transmission of pressure to the laminated thrombus in a saccular aneurysm. Incorrect interpretation might also result when the collateral channels were so located that the aneurysm could not be stilled by pressure without direct compression of these vessels also.

Misleading or actually erroneous concepts could be derived from the reactive hyperemia test if an uninvolved main arterial stem was compressed together with a minor artery which was the site of the lesion. Even under these circumstances, however, it was sometimes possible to locate the lesion definitely and to demonstrate that pulsation, thrill, and bruit could be eliminated while at the same time the blood flow in the main arterial stems remained unaffected. When this could be demonstrated there was little need for anxiety concerning the nutrition of the part after excision of the lesion.

It was sometimes possible, in a patient who presumably had an axillary aneurysm or arteriovenous fistula, to demonstrate that the lesion actually involved the thoracoacromial trunk, the subscapular vessels, or other branches. However, in a single instance the lesion involved not only a minor branch but also the main artery. The patient, observed at the vascular center of Mayo General Hospital, was a 41-year-old soldier who had an arteriovenous fistula

of 6 months duration which was thought to involve one of the circumflex humeral vessels. Bruit and thrill could be eliminated by direct pressure without disturbing the brachial pulse. During operation it was found, as had been thought, that the anterior circumflex humeral artery and vein communicated through a small sac, but it was also found, as had not been suspected, that the superior portion of the axillary artery opened into this sac through a large fistula. The confusion arose because it had been possible to compress the sac in such a manner that the openings from the two arteries and the vein were occluded while the axillary artery itself was left patent. Ligation was required because the damage to the axillary artery was too extensive to permit repair. Consequently, the efficacy of the collateral circulation had to be confirmed during the operation by observing the color and warmth of the hand during prolonged temporary occlusion of the axillary artery with a rubber-shod clamp.

The reactive hyperemia test was frequently performed serially before and after induction of reflex vasodilatation, or before and after sympathetic block or sympathectomy. It was by no means uncommon for a test which had indicated inadequate circulation before one or the other of these procedures, to indicate an adequate circulation after removal of the vasoconstrictor influence.

Miscellaneous Tests of the Collateral Circulation

The tests already described were those chiefly used to test the adequacy of the collateral circulation in the presence of vascular lesions. Two other tests were tried out but were not found sufficiently useful to warrant their continued use. The first was performed by milking the blood from the sub-papillary venous plexus by compressing the arterial lesion while rolling a snugly fitting rubber band from the tip of a digit to its base, then noting the time required for return of color after release of the constricting band. Results were not uniformly in accord with the time components of the reactive hyperemia test.

Another test in this category was performed by simultaneous digital pressure upon the arterial lesion and on some area on a finger or a toe. The time in seconds required for the return of color was compared with the time required for the return of color in the same digital area in the contralateral limb. The test was also carried out without compression of the arterial lesion. The results of this test, like those of the preceding, were not uniformly in accord with the time components of the reactive hyperemia test.

TESTS OF VENOUS FILLING TIME

The simple venous filling test proved of considerable value in demonstrating the rate of circulation in an extremity. It was performed by first elevating the extremity to collapse the veins, then replacing it in the dependent position and noting in seconds the time required to fill the veins on the dorsum of the

hand or foot. Periods up to 10 seconds were considered within the normal range.

However, unreliable results were obtained from this test when vasospasm was present since arterial inflow is slow under these circumstances. Moreover, the results did not distinguish between reduction of blood flow caused by organic arterial involvement and that caused by vasospasm. In order to obtain this differentiation it was necessary to perform the test after injecting 1-percent procaine solution into the appropriate sympathetic ganglia, a supplemental procedure which also furnished useful data concerning the results to be expected from sympathectomy.

The modification of the simple venous filling time test devised by Tuffier and Hallion in 1912⁸ was particularly intended for use in aneurysms and arteriovenous fistulas. As the test was performed at the vascular centers the limb was elevated 30 degrees above horizontal and kept in that position until the veins were well emptied. The aneurysm or arteriovenous fistula was then occluded by digital pressure and a blood pressure cuff, previously placed about the limb distal to the lesion, was inflated to a pressure of 60 mm. of mercury after which the limb was lowered to the horizontal position. If the veins filled within 30 to 60 seconds the collateral circulation was regarded as adequate.

Experience at the vascular centers revealed certain defects in this test. When edema or venous stasis was part of the picture the results were likely to be unreliable. If the veins did not fill well, as frequently happened when vasospasm was marked, an accurate estimation of the venous filling time was impossible. Finally, in some patients, particularly those with large arteriovenous fistulas, venous filling sometimes occurred as soon as the fistula was compressed even though the limb was elevated.

A test to determine the adequacy of the circulation in the fingers or toes (subpapillary venous filling time) was carried out by making firm digital pressure against the ball of the digit for about 3 minutes to empty the blood from the subpapillary venous plexuses. Pressure was then released and the time required for the area to flush was recorded as immediate or normal, slightly or moderately delayed, and markedly delayed.

TESTS FOR SPECIAL CONDITIONS

Varicosities. All the tests employed in Army hospitals to determine the competency of venous valves and the patency of superficial or deep veins are well known and have been extensively used for many years. No new or significant data resulted from their use during World War II. The tests most commonly employed were the Perthes test, the Trendelenburg or Brodie-Trendelenburg test, and the Ochsner-Mahorner comparative tourniquet tests. At the vascular center of Mayo General Hospital it was thought that simple

⁸ Tuffier and Hallion: Sur un procédé permettant de prévoir que l'irrigation sanguine persistera dans un membre après ligature de son artère principale. *Compt. rend. Soc. de biol.* 73: 606, Dec 1912.

observation of venous filling with the tourniquet at various levels of the extremity was more helpful than any other method in determining the site of vascular incompetency in patients with varicose veins.

Scalenus Anticus Syndrome. The scalenus anticus test was used to study the effect upon the subclavian artery of an abnormally small compartment formed by the scalenus anticus muscle and the first rib. Results of this test were regarded as positive if diminution of radial arterial pulsation could be demonstrated while the patient turned his head toward the unaffected side with the chin extended upward. Another test consisted of pulling upward against a weight held in the hand on the affected side in an attempt to extend the arm tensely upward. Diminution of the pulsation of the radial pulse could be demonstrated in this test also. Sole reliance was not placed upon palpation of the pulse or the appearance of the extremity; a cuff was placed over the brachial artery before the test was begun, and additional comparative data secured by means of an oscillogram while it was in progress. In patients with the scalenus anticus syndrome significant tenderness or spasm could sometimes be revealed by simple palpation of the muscle.

Procaine hydrochloride solution was injected into the scalenus anticus muscle in order to confirm the tentative diagnosis of scalenus anticus syndrome and to ascertain the possible effects of scalenotomy. If relief of subjective and objective symptoms followed the injection, the diagnosis was regarded as established and it was concluded that scalenotomy would be beneficial.

Before the solution was injected, the patient was placed in a recumbent position with the head turned to the unaffected side. The scalenus anticus muscle was identified by palpation behind and lateral to the sternomastoid muscle. While the index finger of the left hand palpated the lateral border of the muscle, a needle was inserted into the lateral edge and the muscle was infiltrated with 1-percent procaine solution throughout the lower half, care being taken not to infiltrate the phrenic nerve or brachial plexus. Within 5 to 10 minutes it was usual to find the muscle completely relaxed and the patient temporarily relieved of his symptoms.

Axillary Vein Thrombosis. The objective of tests for axillary vein thrombosis was to demonstrate interference with the return flow of blood from the arm. One very simple test was to observe whether or not the veins collapsed when the patient elevated the affected arm. If thrombosis was present they did not collapse. In another test the patient opened and closed the hands in a pumping motion while the arms were dependent. If thrombosis was present the superficial veins of the forearm became overdistended on the thrombosed side, while on the normal side distention did not occur.

SKIN TEMPERATURE DETERMINATIONS

Since sweating or moisture alters the results of skin temperature readings, all such determinations at the vascular centers were made in rooms in which

temperature and humidity were controllable. The room temperature was kept between 68° and 78° F. and the humidity at 40 percent for basal tests. Readings were made only after the patients had been exposed to this environment for 30 minutes.

Skin temperature determinations were chiefly of value in supplying an objective recording of the actual temperature of a part. They were seldom required for mere diagnosis though they were both valuable and necessary in such difficult diagnostic problems as the determination of possible differences in the mechanism of circulatory disturbances in one extremity as compared to the contralateral one, or in one digit as compared to others. They were also useful in cases in which it was necessary to determine whether the disorder was purely obliterative, had a vasospastic element, or was entirely vasospastic.

Several types of skin temperature meters were in use at the vascular centers. Although all were probably equally efficient, preference as to type varied from center to center.

The skin temperature of certain points on the body was taken routinely in addition to the temperature of whatever special areas might be implicated in the individual patient. The areas tested in the lower extremity were the dorsum of the terminal phalangeal area of each toe, the middorsal area, the midplantar surface, the heel, the intermalleolar region, the ankle, the midleg, the knee, and the midthigh. In the upper extremity the test points were the distal phalangeal portion of each finger, the midpalm, the middorsum, the wrist anteriorly, the midforearm anteriorly, the medial aspect of the elbow, and the midportion of the upper arm anteriorly. A chart indicating each of these points was posted in the controlled temperature rooms to assure uniformity in the skin temperature determinations. Even minute variations in the points at which control and subsequent determinations were made might affect the results. For this reason it was customary to mark with ink or dye the exact points at which initial readings were made so that subsequent readings could be made at precisely the same points. When this precaution was not observed, errors of as much as several degrees Fahrenheit sometimes occurred. The opinion was that such variations might possibly be accounted for by the presence of sizable intracutaneous capillaries at one point and not at another, even though the points of reading might not be more than a millimeter apart.

Psychogenic factors such as nervous tension, excitement, and noise, were found to have a decided influence on skin temperature readings. Every effort was therefore made to reassure the patient and put him at ease. All controlled temperature rooms in which tests were made were soundproof. Repeated determinations were made in cases in which the initial readings were thought to be inaccurate for any of the reasons listed. Successive temperature determinations were also made in some cases to study the effect of changes in the room temperature (Chart 1).

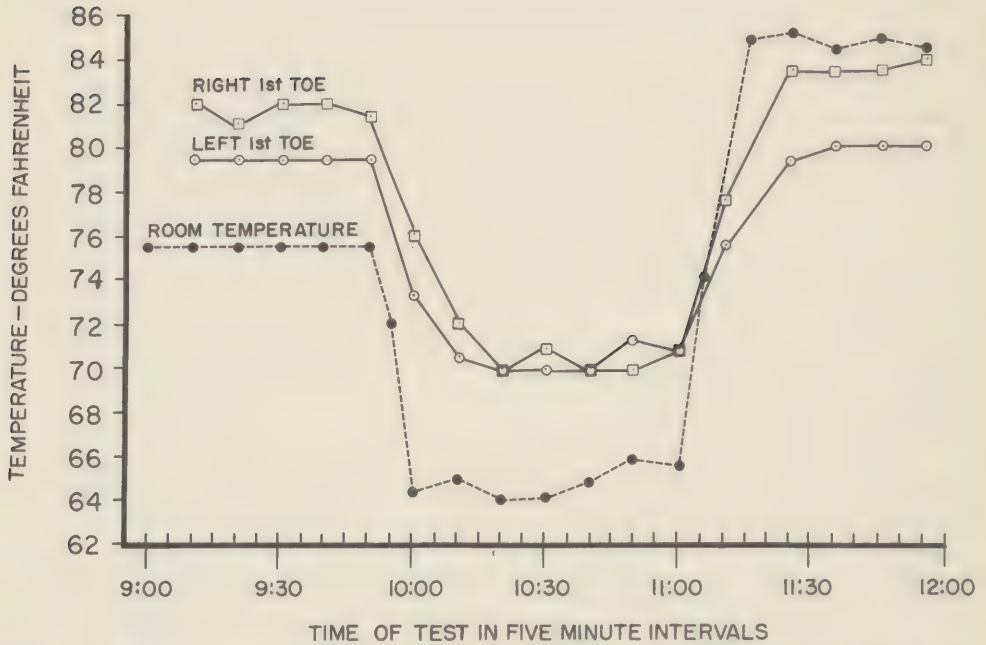


Chart 1. Graphic recording of skin temperature determinations in relation to changes in room temperature.

OSCILLOMETRY

Oscillometric studies were carried out with various instruments such as the Collins nonrecording oscillometer, the Samuels pulsimeter, and the Boullitte, Pechon, and Tycos instruments.

When the manual nonrecording method was used, the cuff of the oscillometer was inflated until the pulse in the extremity was completely obliterated. At this point readings were taken at 10-mm. levels until 0 pressure was reached. In the lower extremity readings were made in the foot, above the ankle, in the leg, at the popliteal level, and at the mid thigh. In the upper extremity readings were taken at the wrist, in the forearm, and in the arm. The maximum oscillation and the level in millimeters at which it was observed were recorded as the oscillometric index (for example, a 7.5 oscillation at 100 mm. was recorded as 7.5/100).

When the recording oscillometer was used, a record was made of oscillations from the level of the pressure at which obliteration of the artery occurred to 0. Readings were in millimeters of mercury. The curves recorded were studied for amplitude and character.

The opinion was expressed at all three vascular centers that while the oscillometer was of some value in the diagnosis of vascular lesions it was neither too reliable nor too useful. The following general observations were made:

1. Most of the patients who had been referred to the vascular centers merely because no dorsalis pedis pulse could be felt on either side in the usual location were found to have better than normal oscillometric readings across the feet. It was the impression that in these patients the lack of detectable dorsalis pedis pulses could be explained by a developmental absence of an anomalous position of the artery.

2. The oscillometer, while seldom necessary for the establishment of a diagnosis or for the evaluation of treatment, was useful in providing an objective recording of the volume of the larger peripheral pulsations and in an occasional difficult diagnostic problem. It was sometimes of value in demonstrating whether obliteration had occurred in a large arterial stem, especially when there were palpable peripheral pulses in the involved limb. This was true in spite of the instrumental lag or error inherent in the test.

3. The oscillometer recorded only gross pulsations as compared with the plethysmographic record which indicated quick pulse volume changes as small as 0.1 cu. mm., or more gradual changes as great as 800 cubic millimeters.

4. The oscillometer was found to give misleading information in arteriosclerosis, and to a lesser degree in thromboangiitis, in that oscillations were sometimes found to be small or absent even when there was a fair or a good arteriolar and capillary circulation. The explanation is obvious: The oscillometer does not depict the circulation in the smaller vessels. Oscillometric readings alone, therefore, could not be accepted as an index of circulatory adequacy but had to be interpreted in the light of other observations.

5. Oscillometric studies of patients with thromboangiitis obliterans frequently proved interesting because they revealed consistent asymmetry of the oscillations of the contralateral limb even when the readings on the poorer side were still within normal limits. This was observed consistently enough to be accepted as a sign in thromboangiitis obliterans. Patients with clinical evidence of migratory thrombophlebitis, but without symptoms of arterial incapacity, also usually presented early asymmetry of oscillations.

6. Oscillometric readings frequently were within the normal limits in patients with trenchfoot and Raynaud's disease.

7. In a number of cases of thromboangiitis obliterans, oscillometric readings were normal even when there were clear-cut signs of impaired circulation in the toes, such as trophic and color changes. It was believed that in these cases the disease had affected only the smaller vessels. In other patients oscillations were reduced in the absence of color changes, while the results of such tests as the reactive hyperemia test and the reflex vasodilatation test showed that the circulation was still normal. In these cases it was thought that occlusion of a large vessel had occurred but that adequate circulation was being maintained through collateral vessels.

SWEATING TESTS

Various tests were employed for the accurate demarcation of areas in which sweating did not occur or was excessive. They were most frequently used in hyperhidrosis, including the variety associated with trenchfoot, but they were also useful in any other condition in which abnormalities of sweating were apparent. They were employed for diagnostic purposes to determine the possible effects of sympathectomy, and as an index of the patient's progress. The starch-iodine test was most useful.

VENOUS PRESSURE DETERMINATIONS

Venous pressure determinations were made in an extensive series of cases at the vascular center of DeWitt General Hospital but furnished no important information except in an occasional case of arteriovenous fistula or arterial aneurysm which was causing pressure on an adjacent vein, or in an occasional case of venous obstruction resulting from either thrombosis or surgical ligation. These determinations were thought to be particularly significant in cases of suspected superior vena cava thrombosis and axillary vein thrombosis.

The only equipment necessary was a venous pressure manometer. Observations were made during rest and during or immediately following exercise. Determinations on patients with thrombophlebitis were sometimes normal in the resting stage while repetition of the test during or after exercise confirmed the suspected obliteration of the veins. In such cases the venous pressure rose above and did not return to the control level for 2 to 3 minutes.

At Ashford General Hospital venous pressure determinations were made in some cases by direct mensuration at the site of an arteriovenous fistula by the introduction of a ureteral catheter through an appropriate vein in the region of the fistula.

DETERMINATION OF THE CIRCULATION TIME

Measurements of the circulation time were made through the introduction of a foreign substance into the blood stream at one point and subjective or objective perception of the time of its arrival at another point. At the DeWitt General Hospital equipment was supplied for the determination of the circulation time by the photoelectric-methylene blue method, but it was concluded that the information supplied by this, as well as by other methods, was not of much practical value.

BLOOD VOLUME DETERMINATIONS

Blood volume determinations were frequently made before and after operation, particularly in patients with arteriovenous fistulas. These studies confirmed earlier observations to the effect that there is an increase in the blood volume in response to the presence of an arteriovenous fistula and a

return to the normal level following obliteration of the communication. Special studies with the dye dilution method and with the ballistocardiograph were made at the Ashford General Hospital and are reported in full in Chapter V.

SKIN RESISTANCE DETERMINATIONS

Determinations of the skin resistance were made in a limited number of cases by means of a portable cutaneous resistance recorder or dermometer. Although this method proved of no practical value in the evaluation of the vascular status of patients with vascular injuries or disease, it did provide significant data concerning the influence of the sympathetic nerves on the vascular system and the possible effectiveness of sympathetic nerve block and sympathectomy. It was also useful in cases in which there was associated loss of sensory nerve supply to an extremity.

PLETHYSMOGRAPHY

It was intended that each of the vascular centers would be supplied with plethysmographs, but these instruments did not reach the point of production and distribution before the end of the war. Although the vascular centers at Ashford and Mayo were able to acquire this instrument, the center at DeWitt, to which the author (A. H. S.) was assigned, was without one during the entire period of its operation. This was unfortunate for while no patient suffered because the instrument was lacking, investigation of the vascular status of many patients would have been expedited had it been available.

This instrument is capable of recording with great quantitative accuracy volume changes in the part under investigation caused by variations in the blood within the small arteries and the arterioles, venules, and capillaries, as well as changes in the intercellular and extracellular fluid and lymph. Plethysmographic recordings reveal with greater accuracy than any other method the differentiation between vasospastic phenomena and phenomena caused by organic occlusive disease, the degree of arterial patency or occlusion, the state of the collateral circulation, and the benefits to be expected from sympathectomy (the latter evaluation being made from observation of the changes produced by sympathetic procaine block).

Plethysmographic studies are reliable only if the test is made under standard conditions. The relative height of the part under investigation greatly influences both the magnitude and the character of volume deflections. All examinations are therefore made with the part in question at heart level. In the recumbent position the toes are essentially at this level, and the fingers are so supported during the test that they are also at this level. The extremity cups must not touch each other since if they do artefacts will occur. The patient must be comfortable for any discomfort will result in tremors and other movements which will be recorded as artefacts. The maximum amount of mental relaxation is essential because psychic disturbances are always reflected in the vascular response. For this reason noise, haste, excitement.

and even the sight of the instrument should be guarded against and the examination should be made under optimum conditions to produce relaxation. These conditions include indirect lighting, a comfortable room temperature, ordinary room furnishings, and calm and confidence on the part of the examiner. If plethysmographic studies are done under any other circumstances, they must be interpreted in the light of the environment.

WHEAL TESTS

The intradermal saline test was employed in a number of cases in an endeavor to determine the adequacy of the collateral circulation in patients with vascular injuries and disease, but it did not prove practical. In this test, if the circulation is good, the wheal should persist for nearly an hour but accurate compression of an artery for this period of time is almost impossible.

The histamine wheal test, which was also devised to estimate the efficiency of the collateral circulation, was not highly regarded at the vascular centers for it revealed nothing which could not be determined equally well by other means, and sloughs of tissue at the site of the injection, sometimes accompanied by ulceration, contraindicated its general use. After the aneurysm or the vessels involved in an arteriovenous fistula had been occluded by digital compression, a drop of 1:1,000 solution of histamine phosphate was placed on the skin of the affected extremity and the area was needled through the drop until a wheal developed. If the collateral circulation was good, the wheal was apparent in 3 to 5 minutes. It was thought that the prompt occurrence of a flare prior to the development of the wheal was as important as the latter phenomenon.

Fluorescin Wheal Test

A method for determining the adequacy of the collateral circulation by means of fluorescin wheal testing was employed with considerable satisfaction at the DeWitt General Hospital by Capt. Theodore B. Massell.⁹ It was based on the similar test developed by Neller and Schmidt¹⁰ to determine the safe level for amputation in limbs which were the site of impending or early gangrene. These observers found that when fluorescin was injected into the veins, sites of minute trauma in an area in which the peripheral circulation was not severely impaired would display brilliant fluorescence, but that no fluorescence would appear if the circulation was inadequate to supply the normal metabolic needs of the tissues. They further found that the area of fluorescence corresponded to the wheal component of triple response to injury as described by Lewis.¹¹

⁹ Massell, T. B.: The fluorescin wheal test for collateral circulation in the preoperative evaluation of patients with aneurysms and arteriovenous fistulas. *Surgery* 21: 636-645, May 1947.

¹⁰ Neller, J. L., and Schmidt, E. R.: Wheal-fluorescence; new method of evaluating peripheral vascular diseases; preliminary report. *Ann. Surg.* 121: 328-337, Mar 1945.

¹¹ Lewis, Thomas: *Vascular Disorders of the Limbs Described for Practitioners and Students*. New York, The Macmillan Company, 1936.

This method was used at the DeWitt General Hospital in a small series of cases to study the vascularity of granulating wounds, particularly in cases of trenchfoot in which there had been spontaneous or surgical amputation of the toes with subsequent granulation of wound surfaces. It was hoped that observations by this method might indicate the degree of vascularization of the granulating tissue more decisively than simple clinical observation, and would thus serve as an index of the optimum time for skin grafting. In the 55 cases in which this method was used to determine the adequacy of the collateral circulation in aneurysms and arteriovenous fistulas, the results were found to be reliable. They so closely paralleled clinical impressions gained by simple inspection, however, that the time and trouble necessary to perform the fluorescein test were not considered justified.

The following conclusions concerning this test were reached at the vascular center of DeWitt General Hospital:

Wheal fluorescence provides a delineation of the end-point of adequate circulation. Comparison is usually possible with the opposite normal extremity so that a control criterion is constantly provided. Movement of the extremity is not necessary during the test and as a result there is little danger that the compressor may slip and erroneous conclusions concerning the collateral circulation be drawn.

Three defects exist in the test which are, however, also present in the reactive hyperemia test:

1. It has limited use in cases in which the compressor cannot be tolerated for anatomic reasons, or in cases in which a sensory nerve is involved in scar tissue at the site of the lesion and compression cannot be tolerated.

2. The compressor may occlude an important collateral branch in the immediate vicinity of the aneurysm.

3. It does not indicate how much activity a patient may enjoy following arterial ligation. Although the collateral circulation may be sufficient to prevent gangrene, ligation of a major artery often results in marked limitation of exercise tolerance because of weakness in an upper extremity or intermittent claudication in a lower extremity. The experience at the vascular center of DeWitt General Hospital suggested, however, that claudication was likely to be more severe in patients whose circulation, by the fluorescein wheal test, was barely adequate rather than good.

TESTS OF VASOMOTOR TONE AND LABILITY OR REACTIVITY

The frequent need for differentiation of vasospastic from obliterative vascular lesions, as well as the need for demonstration of a vasospastic element associated with organic obliterative lesions, required extensive employment at the vascular centers of various methods of testing for the degree of vascular tone and vasomotor lability. Tests most frequently used for this purpose were the reflex vasodilatation test, the basal vascular tone test, immersion of the

hands or feet in ice water, Kerr's trigger reflex test, the cold shower test, and general body cooling test. The specialized technical procedures used for the same purpose, including spinal analgesia, sympathetic block, and peripheral nerve block, are discussed later in this chapter under the heading "Nerve Conduction Interruption Tests."

The reflex vasodilatation test employed extensively at all centers in both vasospastic and obliterative vascular lesions was carried out as follows: The patient was placed in a controlled temperature room in which the temperature was maintained from 68° to 72° Fahrenheit. The distal portion of the extremity to be studied was exposed to this temperature for at least 20 minutes, following which skin temperature determinations were made. Seven or eight hot water bags, filled with water as hot as could be tolerated, were then placed in the axillae and about the abdomen and the patient was wrapped in blankets except for the extremity being studied which was left exposed to the environmental temperature. When it was more convenient a portable body baker was used in place of the hot water bags and blankets. As soon as profuse sweating became evident, skin temperature determinations were made, and repeated at 20-minute intervals for at least an hour and a half.

In the normal person there was a rise of temperature in the digits to between 87.80° and 95° Fahrenheit. This type of response, associated with reduced oscillometric readings, was interpreted to mean that the collateral circulation was good. In the patient with occlusive vascular disease the temperature rise in the digits after body heating was usually only slightly above control initial levels.

The degree of reflex vasodilatation was also useful for studying relief of rest pain and increase in functional capacity as evidenced by lessening of claudication. A modification of this method was employed to test the reactivity to heat and cold. The patient was conditioned for 30 minutes in a controlled temperature room at 75° F. with the humidity kept at minimum saturation. Initial observations of the skin surface temperatures of the upper and lower extremities, together with oscillometric observations, were made for control purposes. The room temperature was then lowered to 65° F. and the patient kept in this environment for 45 minutes. Additional observations of the skin surface temperatures and additional oscillometric studies were made at this time, and repeated after the temperature of the room had been elevated to 85° F. and the patient exposed to this environment for 45 to 60 minutes. Curves were plotted to show graphically the response to environmental changes.

In still another method of testing, the patient was first placed in a controlled temperature room in which temperature was maintained between 68° and 71° F. with the distal portion of the extremity to be studied exposed to the room environment. At the end of 30 minutes, control skin temperature readings were obtained. The patient was then taken into a cold room (usually a large icebox used for the storage of food) in which the temperature varied between

32° and 14° Fahrenheit. He was accompanied by an observer who recorded changes in the appearance of the digits and any symptoms which might develop. At the end of 15 to 20 minutes he was returned to the controlled temperature room where skin temperature readings were repeated.

The precipitation of digital syncope and other symptoms by immersion of the hands or feet in ice water was attempted in patients with Raynaud's disease or other vasospastic conditions. Many patients, however, in whom digital syncope occurred when they went out of doors on a cool day failed to exhibit demarcated pallor following immersion of the affected part in ice water. This experience, which occurred at all the vascular centers, was contrary to what was expected and was never satisfactorily explained. It meant, however, that other methods of inducing digital ischemia had to be resorted to.

Kerr's trigger reflex test was used at the vascular center of DeWitt General Hospital where it proved extremely useful in Raynaud's disease. Both hands were immersed simultaneously, one in water at 59° F. and the other in ice water to which enough salt had been added to reduce the temperature to about 34° Fahrenheit. Invariably the hand immersed in ice water became and remained crimson, while the hand immersed in cool water (59° F.) usually became cyanotic as the result of spasm brought on by *moderate* cooling.

Chilling the entire body in a cold shower bath for 2 minutes almost invariably induced digital syncope in the hands of patients with Raynaud's disease although exposure to room temperature of 48° F. in a controlled temperature room, like immersion of the affected part in ice water, frequently failed to produce this result.

One method employed to determine the degree to which vasospasm contributed to the circulatory stasis was the application of heat to the contralateral unaffected extremity and the measurement of the height to which the temperature (reflex) rose in the affected extremity.

The injection of typhoid vaccine was occasionally employed to release vasoconstriction and to determine capillary dilatability. The ratio between the elevation in the oral temperature and the elevation in the temperature of the extremities following its use was termed the vasomotor index. The test is obviously not selective and was not regarded as of great value in the few cases in which it was employed.

NERVE CONDUCTION INTERRUPTION TESTS

Sympathetic Ganglion Block

Chemical interruption of sympathetic nerve conduction by means of sympathetic ganglion blocks was considered an extremely reliable test at the vascular centers of Mayo and DeWitt General Hospitals where this method was extensively employed. It was regarded as of special value for indicating the contribution of vasospasm to circulatory deficiency and in providing

indications of what might be expected from sympathectomy. At the vascular center of Ashford General Hospital sympathetic block was not thought to be either as practical or as reliable as the spinal analgesia vasomotor test.

Even at the centers in which nerve block was looked upon with favor, however, its limitations were realized. Like all tests for vasospasm it was useful simply in ruling out vascular occlusions. None of these tests indicated the degree of positive vasomotor activity with which the patient would respond to environmental factors or to psychogenic influences.

At DeWitt General Hospital when the lesion was in the lower extremity, 1-percent procaine solution was injected into the first, second, third, and fourth lumbar ganglia first on one side and then on the other. At Mayo $\frac{1}{2}$ -percent procaine was injected singly at the level of the first or second sympathetic ganglion. At DeWitt when the lesion was in the upper extremity procaine was injected into the stellate ganglion, but at Mayo the block was carried out posteriorly at the level of the first dorsal ganglion.

Peripheral Nerve Block

The experience at DeWitt General Hospital warranted the conclusion that observation of the effects of peripheral nerve block on pain, color, temperature, and functional capacity was essential in ruling out arterial occlusion whenever the skin temperature of the affected part did not rise considerably following the application of heat to the body or following sympathetic ganglion block.

The Use of Anesthetic Agents for Testing Purposes

Neither general nor intravenous anesthesia was used for vasomotor testing at any of the vascular centers. Spinal analgesia was employed extensively at Ashford General Hospital where it was thought to be more consistently reliable than sympathetic ganglion blocks and to be attended with fewer complications or unsuccessful results. It was the belief at the other centers that the lowering of the blood pressure likely to occur after induction of spinal analgesia made this test less reliable than selective chemical interruption of sympathetic nerve conduction by sympathetic ganglion blocks.

Spinal analgesia was induced in a patient without preliminary medication and with his stomach empty, after he had been in the controlled temperature room for 30 minutes. At this time control readings of the skin temperature of the lower extremities and oscillometric determinations were made. When they had been concluded, 100 to 120 mg. of procaine hydrochloride were injected into the spinal canal at the interspace between the spinous processes of the fourth and fifth lumbar vertebrae. Analgesia was thus established from a level midway between the umbilicus and the symphysis pubis to the toes. When the complete effects of the injection had been felt, observations were made concerning pain, color, and sweating of the extremities, and the skin temperature and oscillometric readings were repeated.

At the end of the test the patient was returned to his bed on a litter and was kept flat on his back, without pillows, until the following morning. There were no untoward reactions in any of the large number of cases in which the test was used at the vascular center of Ashford General Hospital.

DETERMINATION OF THE BASAL VASCULAR TONE

Studies along the lines of those carried out by Naide¹² to determine the basal vascular tone of patients with vascular diseases and injuries were made at the vascular center of DeWitt General Hospital in the hope that this method of investigation might furnish a more accurate index of vascular tone than could be obtained by other means. Naide had found it necessary merely to observe the skin temperature response in the finger tips during a cooling period in order to classify patients into two basic groups, those with high and those with low vascular tone. A patient was regarded as having a high vascular tone if the hands were cool (below 77° F.) after he had spent 15 minutes, clothed only in a light gown, in a controlled temperature room at 68° Fahrenheit. If, on the contrary, the hands remained warm (77° F. or above) after the exposure, the vascular tone was considered low.

The tests made at the DeWitt General Hospital were carried out during the summer in the early morning when the environmental temperature was comfortably cool. The patients were in a basal resting state, had had no breakfast, and had not been permitted to smoke before the test was made. Skin temperature measurements were made with a galvanometer in a controlled temperature room with the environmental temperature at 68° F. and the humidity at 40 percent. The digital skin temperature was measured at the start of the test and every 10 minutes thereafter over a period of an hour.

Forty-five patients with lesions of the major arteries were studied by this test, 25 before operation for aneurysms or arteriovenous fistulas, 17 after ligation of the main artery to the extremity in the course of operations on arterial lesions, and 3 after ligation of a major artery shortly after injury and development of arterial thrombosis, also after injury.

The results of the test were in agreement with the clinical impression in 32 of the 45 patients. In 10 of the 13 patients in which agreement did not exist, analysis of the end results permitted a comparison of the clinical impression and the results of the test. In 7 of these 10, the test indicated normal or low vascular tone while clinical signs clearly indicated an abnormal degree of vasoconstriction; repetition of the test in several instances did not alter the findings. In another patient the special study indicated high vascular tone while the clinical study and end results indicated absence of vasoconstriction. In the 2 remaining patients the test for basal vascular tone proved superior to the clinical appraisal. In 1 of these patients persistent symptoms of inter-

¹² Naide, M.: Test for vascular tone in humans and its application to the study of vascular diseases with special reference to etiology and prevention of thrombophlebitis. *Am. J. M. Sc.* 207: 606-620, May 1944.

mittent claudication suggested that sympathectomy should be performed even though other clinical evidence of abnormal vasoconstriction was lacking. The other patient, in spite of clinical evidence of increased vasomotor tone, did not develop symptoms of vascular insufficiency. Possibly the fact that the arterial lesion in the latter case was situated in the midfemoral region may have facilitated the development of collateral circulation in spite of the presence of vasoconstriction.

From the experience at DeWitt General Hospital it was concluded that the test for basal vascular tone could not be relied upon alone in the selection of cases for sympathectomy since in a series of 45 cases it proved superior to clinical judgment in only 2 instances, while in 8 others reliance upon it would have dictated incorrect therapy. It was tentatively concluded that the variation in the results of the test at DeWitt General Hospital and those obtained by Naide might be explained by the difference in the character of the case material. All the patients in the Army hospitals were vigorous young individuals who had sustained local vascular trauma. This trauma might well have set up some degree of segmental vascular spasm which was independent of the general vasomotor tone.

ELECTRODIAGNOSTIC STUDIES

Electrocardiograms were made before and after operation in practically all patients with aneurysms and arteriovenous fistulas, as well as those with peripheral arteriosclerosis and thromboangiitis. The marked abnormalities commonly found in patients in civilian practice with arteriovenous fistulas of long duration were unusual among the patients with the same condition examined at the vascular centers. The explanation is undoubtedly twofold: (1) in military practice diagnosis is made early; and (2) fistulas are eliminated surgically before pronounced cardiac damage occurs.

Electro-encephalographic studies were carried out in a few cases of cavernous sinus-carotid artery fistulas both before and after compression to control the passage of blood through the affected artery, but they provided little or no information which could not be obtained by simpler methods.

ROENTGENOLOGIC METHODS

Plain Roentgenograms

Plain roentgenograms of the extremities were employed to demonstrate or exclude (1) calcification in the arteries and veins and in aneurysmal sacs, (2) foreign bodies, (3) subcutaneous trabeculation, and (4) bone changes occurring in conjunction with vascular disease or injury.

Roentgenograms of bones of the extremities often revealed changes in the functional vasospastic group as well as in the organic group of diseases. Osteomyelitis and atrophy of the terminal phalanges associated with ulceration were sometimes observed in thromboangiitis obliterans and Raynaud's disease.

Marked diffuse atrophic changes (osteoporosis) were sometimes observed in the severe acrocyanotic syndrome which followed some cases of trenchfoot. Whether the demineralization was the result of disuse or of a chronic decrease in blood flow remains to be explained. It was usually observed, however, that some improvement in the roentgenologic picture followed use of the limb.

Sudeck's disease, with its pattern of pain, vasospasm, and dysfunction, was associated with a mottled form of decalcification of the bones of the affected limb. The roentgenographic appearance in such cases differed from the smooth type of decalcification observed in disuse atrophy or chronic ischemia. Some observers took the position that smooth atrophy was a transient stage likely to be found in all extremities that had been immobilized for reasons of disease or injury.

Arteriography and Phlebography

Arteriography. Arteriograms (Figs. 3A, B, and C) were used extensively at the vascular center of DeWitt, occasionally at that of Mayo, and never at Ashford. At DeWitt visualization of the arteries was thought to be a valuable method of making precise studies of aneurysms and arteriovenous fistulas both before and after operation and of arteriovenous fistulas and saccular aneurysms during and after spontaneous closure. The end results of arterial reconstruction were also evaluated by this method. Thorotrast (colloidal suspension of thorium dioxide) or diodrast (iodopyracet) were the radiopaque substances used for arterial visualization and there were no serious reactions to the use of either agent, though the injection of diodrast was in a few instances followed by hot flushes, transient nausea and vomiting, or a rash which lasted only a short time. There was also an occasional local reaction. Arteriography was not used at the vascular center of Ashford General Hospital because the staff believed that arteriograms were often misleading and further that serious reactions might result from the use of the agents.

At DeWitt General Hospital both diodrast and thorotrast were used, though thorotrast was preferred if impending gangrene was feared since mild to moderate spasm occasionally followed the use of diodrast. All patients scheduled for either arteriography or phlebography were given a preliminary sublingual, conjunctival, or intravenous test with the agent to be used, and adrenalin was kept at hand for immediate use if a reaction should develop. The technique for both agents was the same. A plain roentgenogram of the extremity was usually taken before the opaque substance was injected in order to determine the optimum x-ray factors to be used.

If the lesion was in the lower extremity the groin was shaved and prepared as for surgery. All exposures were taken in the dorsal decubitus. When the femoral artery had been identified by palpation of the skin crease, a 19-gage needle was inserted and directed obliquely downward at an angle of about 45 degrees to prevent its going through both walls of the artery. As soon as the vessel wall could be felt pulsating against its tip, pressure was decreased and

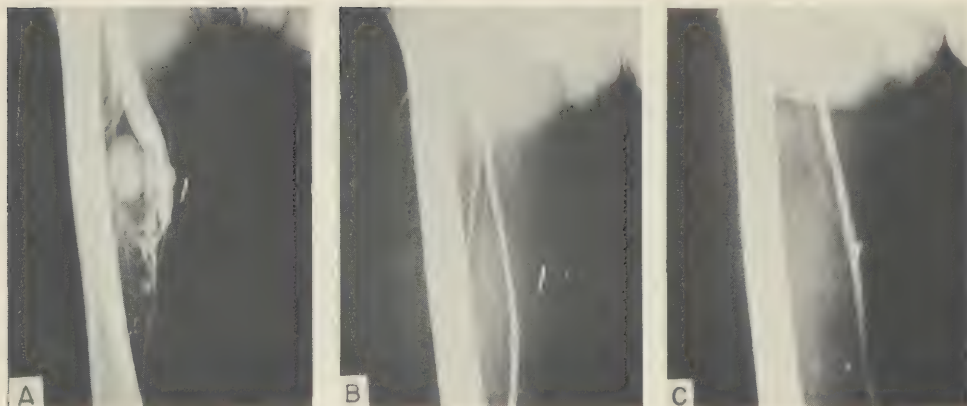


Figure 3. Serial arteriographic study of restorative operation in femoral arteriovenous fistula. A. Preoperative visualization of fistula (22 May 1945). B. Postoperative visualization of right femoral artery after restorative operation on artery and vein (19 October 1945). For this view the opaque substance was injected into the right femoral artery in the groin. C. Postoperative visualization of right femoral vein after injection of opaque substance into vein on medial side of ankle. Note shell fragment in right thigh in all views.

the needle was allowed to rest in that position until with very little additional manual pressure the pulsations forced it into the vascular lumen. Then, as soon as an assistant had compressed the artery proximal to the site of puncture by digital pressure, 25 to 30 cc. of the radiopaque fluid was injected as rapidly as possible and an exposure was made with the film held either in a Bucky tray or an ordinary cassette. Pressure was then released and an attempt was made to obtain another exposure in order to visualize the more distal parts. If the artery distal to the site of an arteriovenous fistula was of small size, the collateral circulation was regarded as adequate.

Arteriograms in other regions were made by the technique described. This was modified, as necessary, to fit the regional anatomy.

Phlebography. Phlebography by means of a contrast medium was not used at Ashford General Hospital for the same reasons that arteriography was not used. It was employed, however, at the vascular centers of both Mayo and DeWitt General Hospitals, 280 examinations being made at the latter. It was the opinion of the staff at both these centers that phlebography, when used with the proper precautions, was free from risk and that it was a valuable method of determining with accuracy the location and extent of venous thrombosis, venous patency or occlusion, and the results of reparative operations on veins. It was thought to be of particular value after restorative operations on veins implicated in arteriovenous fistulas.

The patient was placed on the table in the recumbent position and two films, 14 by 17 inches, were slipped under the affected extremity. The first extended from the groin to the popliteal space and the second, which slightly

overlapped the first, from the popliteal space downward. The upper film was held in a speed cassette in a Bucky tray. The lower was at first placed in a bakelite cassette with the upper metal border removed. Later a wooden stage was employed so that the film could be slipped in and out without moving the leg, and a cardboard holder was substituted for the bakelite cassette.

After the films were in position, a heavy, rubber tourniquet was placed about the upper portion of the thigh and tied just tightly enough to occlude the long saphenous vein. Results were less satisfactory when the tourniquet was applied too tightly. Another smaller, rubber tourniquet was applied just above the ankle and tied tightly enough to make the veins on the foot stand out. The radiopaque fluid was thus prevented from flowing directly into the saphenous system. Veins on the dorsolateral aspect of the foot were preferred as the site of injection since they do not enter the saphenous system directly. Occasionally the tibial vein was exposed at the ankle and the fluid injected directly into it.

Insertion of the needle into the vein was not always easy. Sometimes the patient had to be asked to swing his foot over the side of the table into a dependent position to dilate the veins. The best results were achieved with 20-gage needles and it was important that they be sharp.

After the films had been placed, the tourniquet applied, and the needle inserted, 20 to 30 cc. of diodrast (35 percent) or thorotrast were injected slowly into the vein over a period of 30 to 45 seconds. The tourniquet about the ankle was removed just before the last 5 cc. of material were introduced. While the diodrast was being injected the position of the extremity was readjusted, if necessary, and the leg steadied so that the film could be exposed immediately upon completion of the injection. The tube was centered over the knee, or placed just above it, and the extremity was elevated to the maximum height in order that all of it might be included in the roentgenogram. X-ray factors varied with the size of the patient and the extent, location, and type of vascular lesion, but were usually as follows: tube-target distance 40 inches, milliamperes 100, kilovolts 70 to 80.

After the first picture had been taken, an assistant who had taken up his position before the exposure was made, twisted the tourniquet about the thigh tightly so that most of the dye was held in the extremity while the Bucky tray was being reloaded. The tray was then centered beneath the pelvis underlying the course of the iliac vein, and the x-ray tube was centered to correspond with the new position. The assistant removed the tourniquet from the thigh with a quick, steady movement, and the exposure was made a fraction of a second later. The first films showed outlines of the veins of the thigh and lower leg, and the second the proximal iliac veins and sometimes the lower portion of the vena cava.

Following release of the tourniquet the patient usually experienced a hot flush over the head and neck and sometimes vomited. The reaction was always fleeting.

The same technique was followed for phlebography of the upper extremity. The exposure was usually made while the dye was being injected into the antecubital vein.

Other Radiopaque Techniques

Angiocardiography was not employed at any of the vascular centers. Cerebral angiography and aortography were employed in only a few instances, the radiopaque material being injected into the aorta for the purpose of visualization of the vena cava. Fairly satisfactory results were achieved in a few instances of arteriovenous communication between that vein and the aorta.

Soft-Tissue Techniques

Roentgenologic studies by soft-tissue technique were carried out chiefly when arteriosclerosis of the peripheral blood vessels was suspected. The mere demonstration of calcification of the blood vessels by plain roentgenograms was not considered conclusive evidence of arteriosclerosis obliterans, and confirmation by special techniques was required.

The incidence of calcification of the peripheral blood vessels in young males between the ages of 30 and 40 years was remarkable. At Ashford General Hospital, for instance, between March 1944 and September 1945, 10 of the patients x-rayed for reasons other than vascular disease (or complaints referable to the vascular system) were found to have calcification of these vessels. No patients in the group had any subjective signs of vascular incapacity nor, upon intensive study, could any objective signs of either organic or vasomotor disease be discovered. Oscillometric readings, skin temperature readings, and vasomotor tests were well within the limits of normal.

It was thought significant that none of the roentgenograms of these patients showed a spotty, mottled type of calcification. The shadows in every case were smooth and uniform and gradually faded proximally into the normal portions of the vessels. These observations are in agreement with those of others who have studied calcification in a large series of unselected patients for insurance purposes. It was invariably found that subjects with the smooth type of calcification were relatively or absolutely symptom-free as compared with those who showed the mottled type of calcification.

A number of patients observed at the vascular centers with firm, non-compressible, easily palpable, cordlike peripheral arteries, who might have been expected to show roentgenologic calcification of the vessels, failed to show it. They had, however, other stigmata of generalized arteriosclerosis. They were in a higher age group than the younger men previously mentioned, and their symptoms could reasonably be attributed to cardiovascular degenerative disease. The possibility of generalized atheromatous disease, without visible evidence of calcification, suggested a form of medial sclerosis of the Mönckeberg type.

Teleoroentgenography

Preoperative teleoroentgenograms were made of the heart and aorta in all cases of arteriovenous fistula to serve as controls, and were usually made serially during the postoperative period in order to study changes in the dimensions of the heart after the closure of the fistula. Some degree of cardiac dilatation was usually demonstrable before operation even if the fistula had been present for as brief a period as 2 months, while the shadow was usually greatly reduced in size within a few weeks after the fistula had been closed.

Miscellaneous Roentgenographic Studies

Roentgenologic examination of parts of the body other than the extremities was sometimes carried out, usually by means of radiopaque substances, if it was thought that vascular lesions might be causing filling defects or displacements or distortions of portions of the gastrointestinal tract, the biliary tract, or the urinary tract.

OBSERVATIONS DURING OPERATION

For several reasons, observations concerning the adequacy of the collateral circulation and the effects of temporary occlusion of the affected vessels were made during operation. In a few instances these furnished the only means of determining accurately the status of circulation in the part, the reactive hyperemia test and other preoperative studies having provided equivocal or obviously incorrect information. In the majority of cases, however, investigation during operation was supplemental to the preoperative investigation and was employed (1) to confirm the preoperative conclusion that a major blood vessel could or could not safely be occluded by ligation, suture, or endoaneurysmorrhaphy; (2) to establish the need for immediate sympathectomy or sympathetic ganglion block; and (3) to determine whether all vessels communicating with the arterial lesion had successfully been occluded by the procedure employed.

Observations were made with the artery patent and then with the artery occluded. It was desirable to occlude the vessel at a point just beyond the nearest proximal collateral branch in order to reduce the chance of occlusion of the collateral by progression of a thrombus from the blind arterial sac. Occlusion at this point provided the clearest evidence of the full potential collateral circulation and the best indication of what could be expected following permanent occlusion of the artery. Trial occlusion elsewhere left a blind segment of artery between the site of occlusion and the nearest collateral, and this segment, if of considerable length, might be responsible for sufficient absorption of pulsation to reduce the amount of blood flow through the collaterals.

Trial occlusion was carried out by digital compression or with a rubber-shod clamp or a catheter. The Bethune tourniquet was also useful.

Inspection

When the vascular lesions or the component blood vessels were exposed, significant information was obtained. Simple inspection revealed:

1. The effects produced by prolonged direct occlusion of the involved artery (a) at the site of the vascular lesion, (b) distal to the operative field, and (c) at the proposed site of surgical obliteration.

2. The size and anatomic relationship of aneurysms and arteriovenous fistulas, with and without occlusion of the component vessels.

3. The size and relationship of the component vessels. In general, arteries proximal to an arteriovenous fistula were enlarged, but if the artery distal to the lesion was small then adequate circulation could be assumed to exist.

4. Pulseless aneurysms which occasionally were incompletely filled with blood. Aneurysms with little or no evident pulsation, suggesting obliteration of the sac with organized blood clot, were often found to be far from "dead."

5. The effect of prolonged occlusion of the involved artery on the color of a hand or foot. Color changes proved to be extremely reliable. The period of observation was often 20 to 30 minutes to allow time for full dilatation of the collateral vessels which occupies several minutes, and to allow for the appearance of whatever ischemic manifestations might occur. It had to be borne in mind, if ligation of the artery was done under spinal or general anesthesia, that the vasomotor impulses were in a state of inhibition and regardless of the observations during operation it might be necessary later to eliminate sympathetic impulses if the circulation should be compromised by vasoconstriction.

6. The adequacy of the collateral circulation as manifested by pulsation in or free flow of blood from the distal end of the involved artery during occlusion of the proximal artery. This is known as the Coenen-Henle phenomenon¹³ and was the most widely used method of determining, during operation, the adequacy of the collateral circulation. The observation of a free flow of blood from the distal end of the involved artery was possible only after the aneurysm was opened, which was not done unless there was reasonable evidence of the existence of a satisfactory collateral circulation. This phenomenon indicated only that the local circulation was adequate. It did not necessarily follow that the collateral circulation was adequate throughout the entire extent of the vascular tree distal to the site of arterial involvement. It was also true that adequate collateral circulation could exist throughout the entire extent of the vascular tree distal to this site in the absence of retrograde pulsation or blood flow, the explanation being the presence of a thrombus or the existence of a cicatricial constriction of the artery distal to the point at which it was opened at operation.

¹³ Coenen, H.: Zur Indikationsstellung bei der Operation der Aneurysmen und bei den Gefäßverletzungen. *Zentralbl. f. Chir.* 40: 1913-1916, Dec 1913. Henle, A.: Zur Indikationsstellung bei der Operation der Aneurysmen und bei den Gefäßverletzungen. *Ibid.* 41: 91, Jan 1914.

7. The state of the intima, the possible presence of an inflammatory reaction involving all layers of the vessel wall, and the presence of arteriosclerosis or atheromatosis. This information had much to do with shaping the decision for or against restorative surgery. A final decision often could not be made until the vein and artery had been separated at the site of the fistula. The ragged appearance of the vessel sometimes made it seem impractical or actually impossible to restore the continuity of the vessel, while closer examination reversed the decision by revealing that the vessel wall was pliable and that there was little or no intimal damage. In some instances a considerable loss of substance made it seem unlikely that repair could be done without obliteration of the lumen. If, however, the arterial or venous defect was examined from the standpoint of possible transverse or oblique closure instead of longitudinal closure, a different decision might be reached.

Palpation

Palpation during operation was employed to furnish the following information:

1. Pulsation of the distal arteries following proximal occlusion. The significance of this observation has already been discussed in item 6 under the subheading immediately preceding.

2. Pulsation of an aneurysm or arteriovenous fistula before and after temporary or permanent occlusion of contributory vessels. This observation established which vessels were contributory and also established the effectiveness or completeness with which obliteration of contributory vessels had been accomplished.

3. Thrill, with and without occlusion of contributory vessels.

4. Tension of aneurysmal sacs and the involved vessels or intervening sacs of arteriovenous fistula. High tension in an arteriovenous fistula indicated that the opening into the vein was small.

5. Grossly detectable temperature changes (coolness or coldness) of a hand or foot during a 20- to 30-minute or longer period on occlusion of the exposed involved segment of an artery. In observing the effect of arterial occlusion on the temperature of a part distal to the site of occlusion, it had to be kept in mind that there is a lag of variable duration in the occurrence of full dilatation of collateral vessels following occlusion of the main afferent artery to an aneurysm or arteriovenous fistula, as well as to a part which is not the site of such lesions. Instrumental determination of the temperature was used in some cases.

Auscultation

At the vascular center of DeWitt General Hospital direct auscultation with a sterile stethoscope applied over the lesion was extensively employed during operation, with and without occlusive compression of the component veins and arteries, in an investigation of bruits. The results were frequently

informative but were not invariably dependable for the same reason that the Coenen-Henle phenomenon could not always be relied upon. Direct stethoscopic examinations of aneurysmal sacs were also employed before the conclusion of the operation to be certain that all communications had been surgically occluded, if such a result had been intended.

Intrasaccular Inspection

In the occasional case in which the information definitely could not otherwise be obtained, it was necessary to inspect the inside of the aneurysmal sac to be sure that all vessels communicating with the sac had been identified and occluded. When occlusion of all visible communicating vessels had been achieved, either temporarily or permanently, the sac was quickly incised and bleeding points sought. Speed in opening the sac and locating possible bleeding points after occlusion of the afferent artery was essential if full advantage was to be taken of the delay in complete dilatation of the collateral vessels which follows occlusion of the afferent artery.

Temperature Determinations

At Ashford General Hospital a series of tests for circulation in the lower extremities was made in the course of operations in which the external or common iliac arteries were ligated and divided as part of the surgery for aneurysms and arteriovenous fistulas. For control purposes skin surface temperatures of the toes on both feet were recorded with the patient under spinal analgesia. Similar determinations were made at 5-minute intervals during the operative procedure, the temperature reading being correlated with the precise stage of the operation. It was thus possible to relate the temperature change to the effect of ligation and division of the iliac artery and vein. It was interesting to observe that in spite of complete anesthesia with corresponding inhibition of the sympathetic nerves, the major blood vessels reacted by spasm to manipulation, ligation, and division.

The toes of both feet were again tested after the effect of anesthesia had disappeared and followup temperature readings were made daily for 7 days. At the end of this time the temperature readings of all the toes of both feet were always equal. The patients were then subjected to vasomotor testing in a cold room. Despite the fact that the major arterial stem had been interrupted only 7 days before, the responses to temperature changes were found to be the same in all cases.

Direct Intravascular and Intrasaccular Blood Pressure Determinations

The need had long been evident for some quantitative test for adequacy of the collateral circulation which the surgeon could employ during operation when he felt some doubt about the safety of ligation of the main arterial blood supply to the extremity. Direct measurement of the blood pressure within the aneurysmal sac or distal artery was carried out in 23 cases at the vascular center

of DeWitt General Hospital as a means of supplying such information. The method proved of particular value when the proximity of large collateral arteries to the lesion made preoperative tests of the collateral circulation of doubtful value, or when unsuspected collateral vessels of considerable size were found communicating with the sac and had to be temporarily or permanently occluded before the sac was opened to avoid excessive bleeding.

Since a Hamilton manometer, which would have been ideally suited for intraluminal pressure determinations, was not available, an apparatus for this purpose was devised by Maj. Norman Freeman of the vascular center of DeWitt General Hospital. It consisted of a small 3-way stopcock fitted with short lengths of rubber tubing which connected a 20-gage needle with a 10-cc. syringe. An anaeroid manometer similar to that used with a blood pressure cuff was attached to the third outlet. The instrument, which was not itself sterile, was used in a transparent oiled silk cover which could be sterilized.

After surgical exposure of the lesion the component vessels were encircled with heavy silk thread or rubber tubing. The needle was inserted directly into the artery or into the aneurysmal sac and a small amount (a few cubic centimeters) of physiologic saline solution injected to clear the system of blood. The pressure could then be read directly on the dial. Oscillations of the manometer needle, although small, indicated that the needle was within the blood stream. After the initial pressure had been measured each of the component vessels was temporarily occluded and variations in pressure recorded. In no instance was removal of the needle from the artery or sac attended with bleeding of any consequence.

When this test was used one precaution was always taken: At least 2 to 3 minutes were allowed to elapse after occlusion of the main afferent artery, to permit full dilatation of the collaterals. If this was not done, grossly incorrect conclusions resulted concerning the adequacy of the circulation following major arterial ligation.

The mean initial intrasaccular pressure in the 12 arterial aneurysms studied in this series varied between 110 mm. and 34 mm. of mercury and averaged 84 mm. of mercury. In the 11 arteriovenous fistulas the mean initial pressure varied between 70 and 30 mm. of mercury and averaged 40 mm. of mercury. In aneurysms, constriction of the afferent artery caused a fall in the intrasaccular pressure to an average of 58 mm. of mercury, while in fistulas a similar procedure caused an average fall of 10 mm. of mercury. It was found that with a pressure of 32 mm. of mercury tissue survival could be expected. This is in accord with Korotkow's observation that a pressure of 30 mm. of mercury is adequate.

CHAPTER III

Acute Battle-Incurred Arterial Injuries

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and

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Acute injuries of the major arteries have always constituted one of the most serious problems of military surgery. They are associated with a high immediate death rate and not infrequently result in permanent disability. It is curious, therefore, that so little information is available concerning them.

When the United States became actively involved in World War II, the majority of medical officers knew practically nothing about vascular injuries. Few factual data were available because this type of injury occurs infrequently in civilian practice and because the recorded experience of previous wars was meager. In the official American history of World War I are contained data on the gross incidence of arterial wounds¹ and brief general statements regarding the management of the injured artery and vein,² but no information is provided regarding the results of arterial wounds in relation to the characteristics of the injury and the type of treatment. Very few medical officers were familiar with the British experience concerning arterial injuries in World War I as recorded by Makins.³

In the years which elapsed between World War I and World War II numerous advances were made in vascular surgery, but they were confined to the small groups of surgeons who were interested in this field and who developed new methods or applied to it developments which had been made in other fields. The principles of debridement were clarified and standardized. Chemotherapeutic agents of great effectiveness were introduced, as were vasodilating and anticoagulant agents. Sympathectomy had become a recognized therapeutic procedure in selected cases of vascular insufficiency. Yet in spite of these advances the results secured in arterial injuries in World War II, at least in the first months of American participation, were no better than those

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¹ Love, Albert G.: Statistics. *The Medical Department of the United States Army in the World War.* Washington, Government Printing Office, 1927, vol 11, pt 1, p. 57-85.

² Pool, Eugene H.: Wounds of soft parts. *In The Medical Department of the United States Army in the World War.* Washington, Government Printing Office, 1927, vol 11, pt 1, p. 302-303.

³ Makins, G. H.: Injuries to the blood vessels. *In Official History of the Great War Medical Services. Surgery of the War.* London, His Majesty's Stationery Office, 1922, vol 2, p. 170-296.

reported by Makins in World War I and in some respects were actually worse. This anomalous situation is explained, at least in part, by the general ignorance of medical officers concerning the principles of management of vascular injuries.

It is only fair to point out that the unhappy experiences of American surgeons with arterial injuries were not unique. In a conference of British surgeons held in Cairo in August 1943, Ogilvie⁴ reported that in the course of the war he had observed no instance of ligation of the popliteal artery not followed by gangrene. Blackburn⁵ in 1944 made substantially the same statement. British experiences in World War II thus did not support the observations of Makins in World War I. He had reported that amputation was necessary in only 43.1 percent of 144 casualties with wounds of this artery.

When medical units were activated in the United States after the attack on Pearl Harbor much of their basic training was devoted to such matters as the use of the Lyster bag, the construction and disposition of slit trenches, map reading, military protocol, and other nonmedical subjects. Medical instruction was limited chiefly to hospital administration. It included very little concerning the management of combat-incurred wounds. Medical officers learned practically nothing of the American medical experiences of World War I as they were recorded in the official history of that war or of the valuable experiences of Allied medical personnel in the early years of World War II. As a result, American medical officers were sent to the various fronts with a certain amount of information concerning court-martial proceedings, sanitation, and similar matters, but with almost no factual information upon the pathology and therapy of war wounds.

The general ignorance concerning the management of combat-incurred vascular injuries and the complacency felt concerning them by those who were familiar with Makins' observations and conclusions were in no wise altered by the appearance, in 1943, of a *Military Surgical Manual*⁶ containing a section on vascular injuries. Valuable as was some of the information it contained, other material in this manual was quite misleading. In one table, for instance, the source of which was not stated, the expected percentage of gangrene or other disturbance was set forth for sudden ligation of various arteries. Ligation of the aorta was stated in this table to be associated with a 100-percent incidence of gangrene, and that of the common iliac artery and of the posterior tibial artery (when both bones of the leg were fractured additionally) with an incidence of 50 percent. But ligation of the popliteal artery with its concomitant vein, according to this table, was never followed by gangrene. The figures presented in the table, the text stated, ". . . are rather out-of-date. Today, by simultaneous division of the companion vein and by performing

⁴ Ogilvie, W. H.: War surgery in Africa. *Brit. J. Surg.* 31: 313-324, Apr 1944.

⁵ Blackburn, G.: Surgery in the field. *Lancet* 1: 361-365, 18 Mar 44.

⁶ National Research Council, Division of Medical Sciences. Burns, Shock, Wound Healing and Vascular Injuries. Prepared under the auspices of the Committee on Surgery of the Division of Medical Sciences of the National Research Council. *Military Surgical Manuals*, vol 5. Philadelphia, W. B. Saunders Co., 1943.

sympathetic procaine block, several times if necessary, to avoid vasoconstriction and to encourage the collateral circulation, the chances of gangrene are much smaller."

Later in the text, in a detailed discussion of ligation of the popliteal artery, the following statements were made: "The artery can be doubly ligated and divided with impunity in the upper part of its course but with less safety in its lower portion, close to its division. Apparently the most danger is encountered in those cases in which hematomas have been present for many hours or days before treatment is instituted. Among such, gangrene of the foot is rather common."

Medical officers who relied upon these data were naturally disappointed when their results did not approximate those given. Furthermore, in some series of arterial wounds observed during the Tunisian campaign, gangrene followed injury to the popliteal artery in almost all cases; a finding in direct contrast to the results cited in the manual which was in press at the time.

Constant attention to details of wound management, constant dissemination of information, repeated practical demonstrations of techniques by the surgical consultants and their assistants in the Mediterranean and European Theaters of Operations were eventually supplemented by information from the Office of The Surgeon General. As the concept of arterial injuries became more nearly correct there was some corresponding improvement in therapeutic results. That the improvement was not more pronounced is an index of the essential seriousness of this type of injury. Toward the close of the war the amputation rate in interruptions of the popliteal artery, for instance, was closer to 75 percent than to the 100 percent it had been in the beginning, but it cannot truthfully be said that the results in this or in most other acute arterial injuries were ever really satisfactory.

INCIDENCE

The incidence of acute arterial injuries is admittedly low in all recorded wars, but such statistics as are available generally seem to underestimate their frequency. Even in World War II, when a real effort was made to report the figures accurately, the data were still deficient in certain respects. This lack of information is not difficult to explain: For obvious reasons, vascular injury is seldom recorded as a primary diagnosis and in many instances, including both the most serious and the least serious cases, it is probably not recorded at all. In many reports, cases which came to amputation as the result of such complications of arterial wounds as life-endangering infection, such as gas gangrene, are not recorded as arterial injuries. In addition, analysis of the available statistics requires considerable caution. Most series are actually or relatively small, and many from previous wars include both acute and chronic conditions. In drawing conclusions from them, therefore, many qualifying circumstances must be taken into account.

Previous Wars

Available statistics (Chart 2) suggest that the incidence of arterial injuries among battle casualties of previous wars was extremely low. It was approximately 0.29 percent in the Civil War,⁷ and 0.8 percent, according to LaGarde, in the 1,400 injuries sustained at Santiago during the Spanish-American War.⁸ In the Russo-Japanese War,⁹ a few years later, it was reported as 2.4 percent.

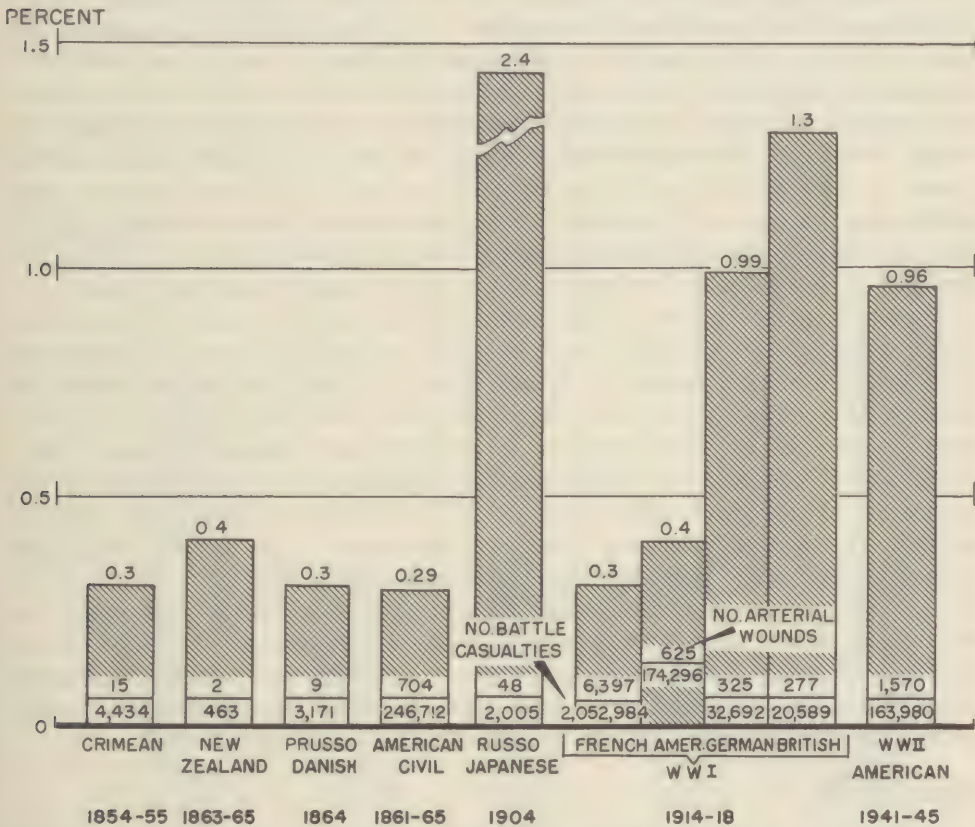


Chart 2. Incidence of arterial wounds among battle casualties in various wars. Nature and source of these data are indicated in text, pp. 63-65.

⁷ Otis, George A., and Huntington, D. L.: The Medical and Surgical History of the War of the Rebellion. Surgical History. Washington, Government Printing Office, 1883, vol 2, pt 3, pp. 763, 765. In the official history are recorded 485 cases of primary lesions of blood vessels out of 2,235 cases "in which the bleeding vessels were definitely ascertained." It should be understood that some of these may have been cases of "secondary hemorrhage" in which the artery may not have been directly wounded. The incidence reported by DeBakey and Simeone in Annals of Surgery 123: 534-579, Apr 1946, omitted such possible cases. On the assumption that the same proportion held for the remaining 1,010 cases in which the blood vessels involved were not named, the 485 would have been expanded to 704.

⁸ LaGarde, Louis A.: Gunshot Injuries: How They Are Inflicted, Their Complications and Treatment. New York, William Wood & Co., 1916.

⁹ Macpherson, W. G.: Report 14. Port Arthur: The Russian Red Cross Society's Hospital: Statistical Analysis of 2,080 Wounds Treated During the Siege. The Russo-Japanese War. London, His Majesty's Stationery Office, 1908, p. 281-291.

Despite the lack of clinical discussion of vascular wounds in the official American history of World War I, the available information indicates that the incidence of this type of wound among American troops was about 0.4 percent of battle casualties.¹⁰ The British official history,¹¹ in spite of the extensive discussion of the subject which it contains, supplies no data concerning incidence and Makin's classic monograph¹² is no more helpful. His material, in fact, is quite misleading unless it is remembered, as will be emphasized later, that it includes nonacute as well as acute injuries. It is limited to 1,191 cases and consists of 2 series. One comprises 668 cases handled by numerous individual surgeons in the British Isles and overseas and obviously includes nonacute as well as acute injuries. The other consists of 523 cases observed in France by a single surgeon. Makins himself warned that only modified reliance could be placed on any deductions drawn from this material. Almost the only data available on the subject of arterial injuries per se among British troops in World War I are in Bowlby and Wallace's report¹³ of 277 ligations of major arteries (1.3 percent) in 20,589 casualties treated at a single casualty clearing station.

According to Maurer,¹⁴ 443 wounds of the blood vessels, 17 percent of which involved only the veins, were observed among 8,000 wounded treated in a French ambulance service in World War I. When the wounds which are exclusively venous are excluded, the incidence of arterial injuries in this series was 4.6 percent. Mignon's figures¹⁵ for 6 French ambulances (so stated that a tabulation is possible) show 399 vascular injuries, 2.0 percent, among 19,734 wounded. The French official history of World War I¹⁶ lists 6,397 vascular injuries (0.3 percent) among 2,052,984 casualties. The German incidence, according to Franz,¹⁷ was three times as great, 0.99 percent.

Matas,¹⁸ in his treatise on vascular injuries, stated that 24.7 percent of all battle casualties treated in forward hospitals had injuries of the blood vessels and that 2 percent of all wounded admitted to base hospitals presented traumatic aneurysms. He does not indicate the source material for this incidence, which is the highest recorded, nor does he identify the casualties involved.

World War II

Statistics for World War II are considerably more complete. Figures for some of the armies during certain portions of the fighting in Italy, in Western

¹⁰ See footnote 1, p. 60.

¹¹ See footnote 3, p. 60.

¹² Makins, G. H.: *On Gunshot Injuries to the Blood Vessels*. Bristol, John Wright & Sons, Ltd., 1919.

¹³ Bowlby, A., and Wallace, C.: The development of British surgery at the front. *Brit. M. J.* 1: 705-721, 2 Jun 17.

¹⁴ Maurer, A.: Wounds of the vessels of the face, neck and limbs; their surgical treatment, based upon four hundred and forty-three cases. *Internat. Clin.* 1: 164-195, 1921.

¹⁵ Mignon, A.: *Le Service de Santé pendant la Guerre, 1914-1918*. Paris, Masson & Cie., 1926, Tome 2.

¹⁶ Ministère de la Guerre. Direction du Service de Santé. *Étude de Statistique Chirurgicale Guerre de 1914-1918*. Paris, Imprimerie Nationale, 1924.

¹⁷ Franz, Carl: *Lehrbuch der Kriegschirurgie*. Dritte Auflage. Berlin, Springer-Verlag, 1942.

¹⁸ Matas, R.: *Endo-aneurysmorrhaphy*. I. Statistics of operation of endo-aneurysmorrhaphy. II. Personal experiences and observations on the treatment of arteriovenous aneurysms by the intrasaccular method of suture; with special reference to the transvenous route. *Surg., Gynec. & Obst.* 30: 456-459, May 1920.

Europe, and in the Pacific and China-Burma-India theaters, reveal 1,570 vascular injuries among 163,980 battle casualties (Chart 3).¹⁹ At the time these data were analyzed, figures from First and Ninth Armies were not available. Experience cited for Third, Fifth, and Seventh Armies is that for which break-down of arterial injuries was available. The annual reports of the surgeons of those armies indicate that the total numbers of battle casualty admissions to hospital and quarters during the entire war were 91,000, 73,000, and 84,000, respectively. The total incidence of 0.96 percent in the samples is remarkably close to the incidences reported from the separate theaters and armies. Similar correspondences noted in the distribution of vascular wounds (1,564) among wounds of the extremities (108,405) observed in the separate theaters and armies suggest that the overall incidence of 1.4 percent is fairly representative (Chart 4).

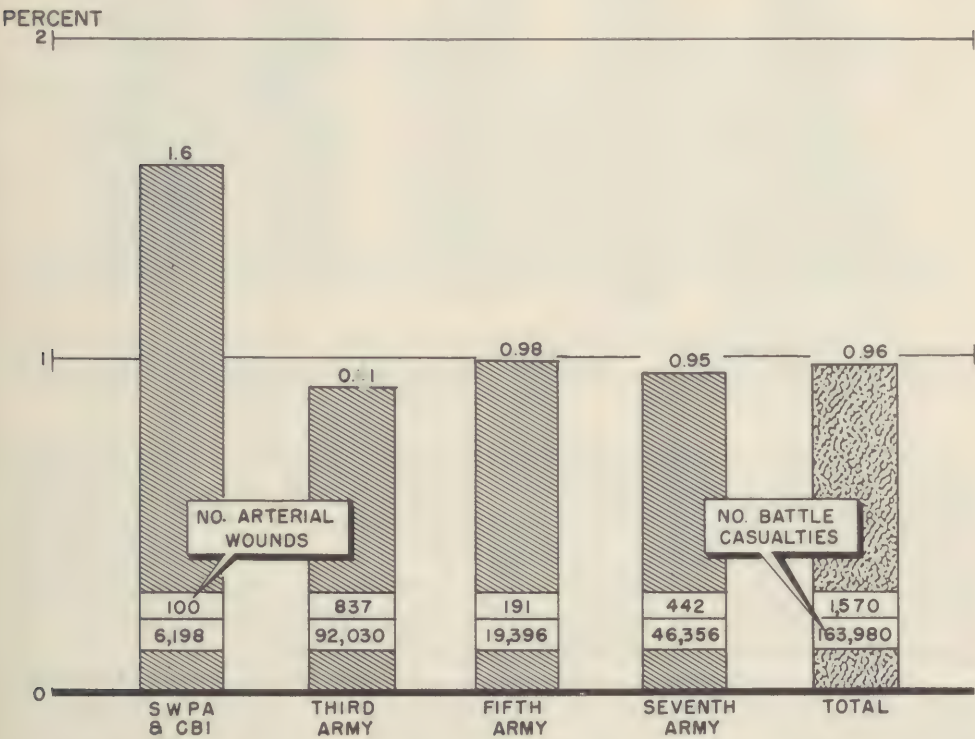


Chart 3. Incidence of arterial wounds among American battle casualties in World War II. Figures are based on samples as available and are not to be considered as complete. See text, pp. 64-65 for details of selectivity.

¹⁹ Preliminary data based on sample tabulations of individual medical records indicate that during 1944 and 1945 (the only years for which such data are presently available), in the total Army, there were 12,600 battle wound and injury admissions with artery involvement, or about 1.7 percent of the approximately 760,000 battle wound and injury admissions to hospital and quarters. Expansion of the data to include arterial injuries among battle and nonbattle wounds and injuries produces a percent of 0.8 for the 2-year period.

PERCENT

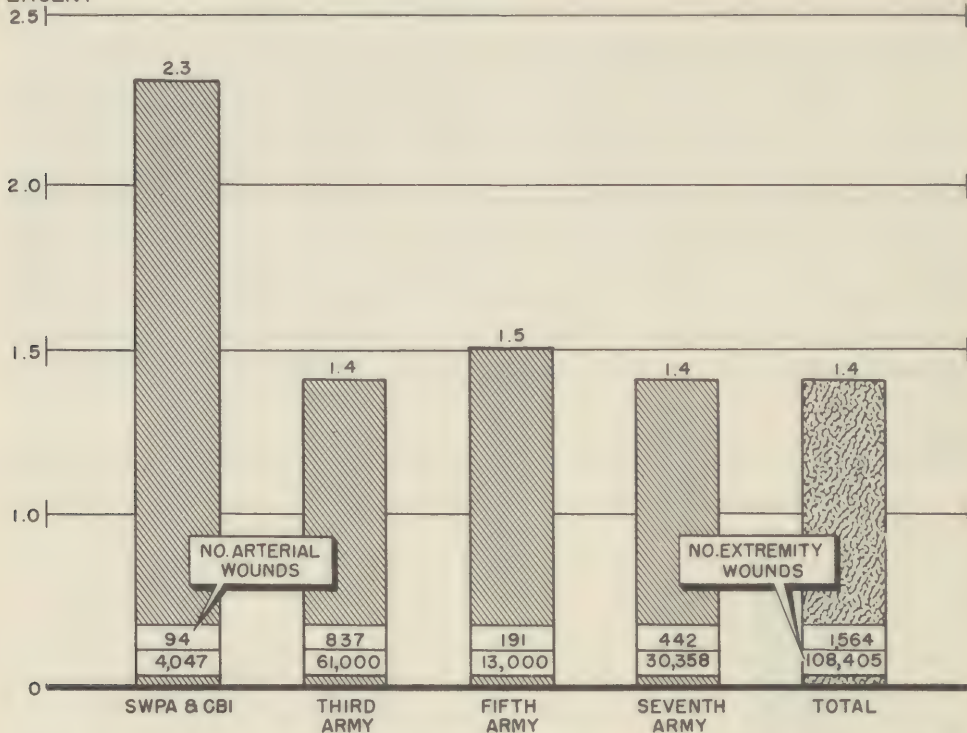


Chart 4. Incidence of arterial wounds among wounds of the extremities in American battle casualties in World War II. Figures are based on samples as available and are not to be considered as complete. See text, pp. 64-65 for details of selectivity.

As these statistics show, the total incidence of vascular wounds among all casualties has been relatively and absolutely small in all wars. Even the large numbers of wounded in World War II do not make the absolute number of vascular wounds very large. The significance of the figures lies not in the actual incidence but in the threat which these wounds carry to life and limb. Only by examining the frequency with which these injuries appear as the indication for amputation will their importance be realized. (Chart 5.)

Incidence in Relation to Amputation. No significant statistics compiled from this point of view seem to have been recorded, but accurate data for World War II are available from the Mediterranean and European Theaters of Operations (Chart 5). Among 3,177 major amputations performed in these theaters, 2,179 (68.6 percent) were the result of extensive trauma, 380 (11.9 percent) resulted from clostridial myositis or other serious infections, and 618 (19.5 percent) followed major arterial injuries. Records which became available with the capture of a German amputation center showed that among 1,359 major amputations, 64.3 percent were the result of trauma, which is close to the American incidence of 68.6 percent. Thereafter the German figures are not in

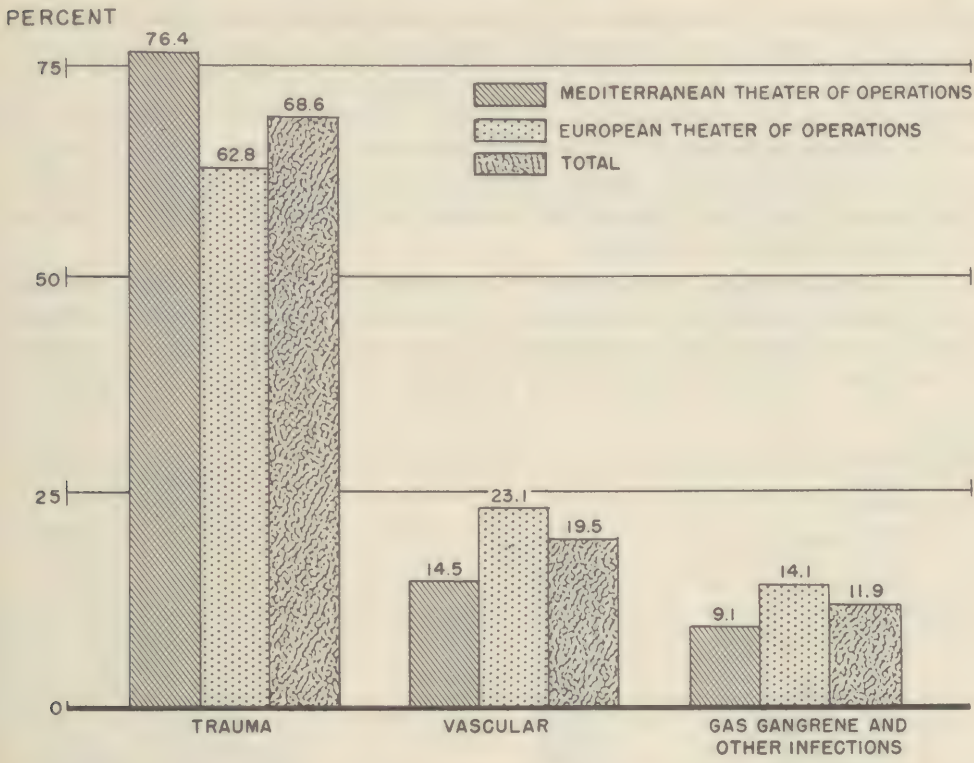


Chart 5. Causes of amputation among American battle casualties in World War II. Figures are based on samples as available and are not to be considered as complete. See text, pp. 64-65, for details of selectivity.

agreement with the American; 29.7 percent of the German amputations were the result of clostridial myositis and only 6 percent followed vascular injuries. Corresponding figures on the Russian experience reported by Kramarov²⁰ showed trauma to be the cause of amputation in 16 percent of the cases, gas gangrene and other infections in 79 percent, and vascular injury in 5 percent. The striking difference between the incidence of infection as a cause for amputation in the American series and in the other series may be interpreted as reflecting the excellence of the surgery done by American surgeons in forward areas. The percentages of amputations because of vascular trauma provide a true concept of the magnitude of the problem and also indicate the inevitability of the great majority of amputations for these injuries.

Regional Distribution. An analysis of the relative frequency with which various arteries are involved in battle casualties (Chart 6, Table 3) shows that the brachial, tibial, femoral, and popliteal arteries are involved far more often

²⁰ Kramarov: Quoted by Aird, I.: A review of recent Russian studies of gunshot wounds of the thigh. Bull. War Med. 4: 619-620, Jul 1944.

than any others. They accounted for 70 percent of the total vascular injuries reported by Makins²¹ in World War I and for 85 percent of those sustained by American troops in 3 overseas theaters of operations in World War II. The explanation of this preponderance is simple: Casualties suffering from injuries of larger arteries frequently did not live long enough to reach medical installations and therefore do not appear under precise diagnoses in medical statistics. Furthermore, injuries of less critical arteries were frequently not discovered or, if discovered, were not recorded.

A comparison of the frequency of wounds of the brachial, tibial, femoral, and popliteal arteries in the combined British and American statistics for World War I and in the American statistics for World War II shows that the incidence of wounds of all four arteries as a group was about the same in World War

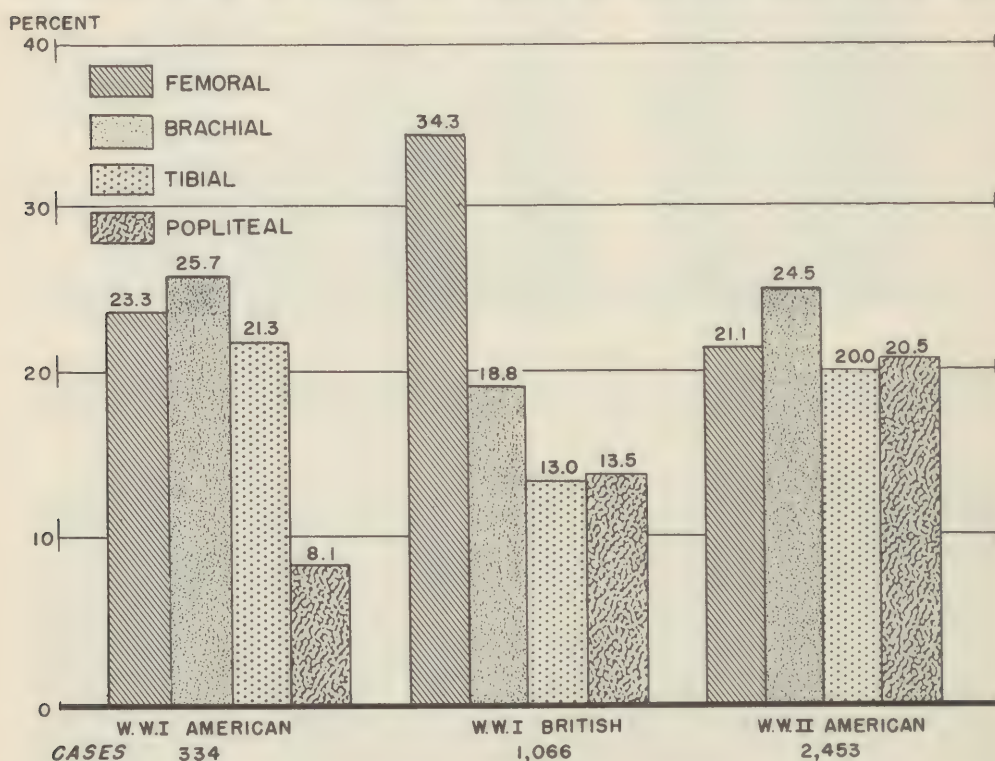


Chart 6. Distribution of arterial wounds according to anatomic location in wounds of the extremities in various wars. Figures are based on samples as available and are not to be considered as complete. See text, pp. 63-65, for details of selectivity. Incidences in this chart, it should be emphasized, are based only on arterial wounds of the extremities, whereas those shown in Table 3 are based upon all arterial wounds. Arteries of the head and neck and renal arteries have been excluded.

²¹ See footnote 3, p. 60.

TABLE 3. COMPARATIVE DISTRIBUTION OF ARTERIAL INJURIES AMONG WORLD WAR I (BRITISH) AND WORLD WAR II (AMERICAN) CASUALTIES

Artery	British World War I (Makins ¹)				American World War II			
	Total injuries		Loss of limb ²		Total injuries		Loss of limb ²	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Aorta.....	5	0.4	5	100.0	3	0.12	2	66.6
Carotid.....	128	10.7	38	29.6	10	0.4	3	30.0
External carotid.....	0	-----	0	-----	3	0.12	-----	0
Renal.....	0	-----	0	-----	2	0.10	2	100.0
Vertebral.....	3	0.2	0	-----	0	-----	-----	0
Subclavian.....	45	3.7	4	8.8	21	0.85	6	28.6
Axillary.....	108	9.0	5	4.6	74	3.0	32	43.2
Brachial.....	200	16.7	12	6.0	601	24.3	159	26.5
above profunda.....	0	-----	0	-----	97	3.9	54	55.7
below profunda.....	0	-----	0	-----	209	8.5	54	25.8
Radial-ulnar.....	59	4.9	3	5.0	0	-----	-----	0
radial.....	0	-----	0	-----	99	4.0	5	5.1
ulnar.....	0	-----	0	-----	69	2.8	1	1.5
Radial and ulnar.....	0	-----	0	-----	28	1.1	11	39.3
Common iliac.....	1	0.1	1	100.0	13	0.5	7	53.8
External iliac.....	4	0.3	0	-----	30	1.2	14	46.7
Internal iliac.....	1	0.1	0	-----	1	0.05	-----	0
Femoral.....	366	30.5	74	20.2	517	20.9	275	53.2
above profunda.....	0	-----	0	-----	106	4.3	86	81.1
below profunda.....	0	-----	0	-----	177	7.2	97	54.8
profunda.....	0	-----	0	-----	27	1.1	-----	0
Popliteal.....	144	12.0	62	43.1	502	20.3	364	72.5
Anterior tibial.....	26	2.2	1	3.8	129	5.2	11	8.5
Posterior tibial.....	97	8.1	9	9.2	265	10.7	36	13.6
Anterior and posterior tibial.....	7	0.6	2	28.6	91	3.7	63	69.2
Peroneal.....	4	0.3	2	50.0	7	0.28	1	14.3
Anterior tibial and peroneal.....	3	0.2	0	-----	0	-----	-----	0
Posterior tibial and peroneal.....	1	0.1	0	-----	5	0.20	2	40.0
Both tibials and peroneals.....	0	-----	0	-----	1	0.05	1	100.0
Total.....	³ 1,202	-----	218	18.1	2,471	-----	995	40.3

¹ The figures compiled from Makins' tables represent combinations of his totals for the categories of gangrene and amputation, this plan being adopted to obtain the maximum number of cases without possible duplications. The numbers represent the minimum number of patients who must have had amputations.

² The figures for the aorta, the carotid, and renal arteries indicate the number of patients who died or developed cerebral complications.

³ This total differs from the total of 1,191 cases in Makins' master table because of the addition of 11 injuries of vessels of the leg secured from a detailed table presented in the text.

II as in the previous war. However, in World War II the incidence of wounds of the popliteal artery was higher than the incidence recorded previously. The reason for these differences can only be surmised. Methods of recording were probably more exact in World War II. Certainly in this war there was a greater

and more selective interest in vascular injuries than had been exhibited in previous wars. Finally, in World War II there was greater emphasis on conservation of limbs than in other wars of history.

POLICIES OF MANAGEMENT

North African and Mediterranean Theaters of Operations

In the North African and Mediterranean Theaters of Operations specific directives were not issued for the treatment of vascular injuries, but no opportunity was lost to disseminate information concerning such injuries.²² Case teaching and technical demonstrations were also carried out by the surgical consultant for the theater and by his assistants on their visits to both forward and base hospitals. The following principles were emphasized:

1. Careful debridement in all cases with excision of all devitalized tissue and preservation of all undamaged vessels however small.

2. Adequate incision to permit clear visualization of all structures implicated in the wound and to avoid out-of-sight manipulations.

3. Exploration of all major vessels whenever there was evidence of circulatory insufficiency in an extremity whether the artery lay directly in the track of the missile or at some distance from it.

4. Procaine block of the sympathetic nerve supply to the extremity to relieve spasm of the major vessels whenever it was suspected, or to improve the collateral circulation to the limb when the main arterial supply had to be ligated or manipulated.

5. Lumbar ganglionectomy for serious lesions of the major arteries of the lower extremities whenever conditions permitted this procedure. For injuries of vessels of the upper extremity sympathetic denervation other than by means of procaine block was not recommended. This operation is too specialized to warrant its performance in the field, and the incidence of gangrene following interruption of major arteries of the upper extremity was so much less than the incidence in the lower extremity that it was not regarded as necessary.

6. Suturing the arterial lesion whenever conditions were favorable.

7. Arteriectomy, thrombectomy, and other operations according to the indications of the individual case.

Part of the teaching, in circular letters and in person, was concerned with methods for controlling hemorrhage. Warnings were issued against the use of tourniquets without special precautions, and the dangers of gauze packs were also emphasized. If a pack was necessary, the desideratum was that it be removed at the earliest opportunity and that a notation of its use be made

²² (1) Cir Ltr 13, Office of the Surgeon, NATOUSA, 15 May 43, sub: Memo on forward surgery. HD.

(2) Cir Ltr 46, Office of the Surgeon, NATOUSA, 29 Aug 44, sub: Surgical management of the wounded (111). HD.

(3) Cir Ltr 8, Office of the Surgeon, MTOUSA, 10 Mar 45, sub: Notes on care of battle casualties. HD.

on the soldier's record. The preferable method of controlling hemorrhage from major vessels was stitch ligature.

In the hope that an adequate collateral circulation would develop, early operation for aneurysm or arteriovenous fistula was not recommended. The only justification for early operation in this overseas theater was the arrest of hemorrhage or some similar emergency. A deep hematoma, however, which was impeding the circulation, was to be dealt with immediately.

European Theater of Operations

In the *Manual of Therapy*²³ prepared before D-day, for the European Theater of Operations, the following instructions were given for the management of wounds of the large blood vessels:

Diagnosis:

1. Diagnosis is made by bright blood escaping from wound or an increasingly tense hematoma.
2. Remember that the skin need not be broken in order for an injury to an artery from a contusion, a fracture or a dislocation to be present.

Treatment:

1. *Control hemorrhage* in cases in which blood is escaping from the wound by any of the following methods:

- a. Elevation of the part. This should be done with due care of associated fractures, regardless of the local methods used.
- b. Direct pressure on the wound with a bulky dressing.
- c. Secure the bleeding vessel with a clamp and ligature, and ligate the companion vein. This is only to be done when the open vessel can be easily seen in the wound, lest blind clamping in the depths of the wound cause nerve injury.
- d. Direct control of the artery by digital pressure at the root of the limb.
- e. Ligation of the artery and companion vein at a distance from the wound.
- f. The use of a tourniquet is to be discouraged except as a temporary emergency measure to facilitate control by other means, i. e., ligature, packing, and pressure dressing. Evacuation with a tourniquet in place means the almost certain loss of the extremity distal to the tourniquet. However, during evacuation, an unapplied tourniquet should accompany patients with injuries to major blood vessels.

2. In cases in which the bleeding is chiefly subcutaneous, local pressure over the hematoma is the only emergency local measure indicated.

3. Cases with severe bleeding into fascial planes of the extremity have a greater chance of gangrene than those in whom the blood can escape. Priority evacuation is indicated in these cases.

4. Replace lost blood, whether external or into tissues, with plasma and blood transfusion.

5. For transport, keep the body warm but apply no artificial heat to the limb.

6. *Surgical technique for the ligation of important arteries.* The following technical steps should be employed in approaching individual blood vessels. The incisions depicted are those suitable for reaching the vessels at a point where they are undamaged. Where the approach is through a wound directly onto the lesion in the vessel, incisions should be much larger than those here shown, in order to give enough exposure for adequate control of hemorrhage. The decision as to the site for ligation is best made by constriction of the artery in the wound with observation of the color, pulse, and temperature in the hand or foot during constriction. This is safer than relying on a constant pattern of collateral circulation in a system so subject to anomalies as the arterial tree.

²³ Manual of Therapy, European Theater of Operations, 5 May 44.

The *Manual of Therapy*²⁴ for the European Theater of Operations also set forth the following general principles for the definitive surgical treatment of vascular injuries:

1. Cases of large increasing hematoma not controlled by pressure should be explored. Evacuate the hematoma and ligate the involved vessel.
2. Divide the artery between two ligatures and, for additional security, transfix both stumps with a ligature. Division of the artery permits more accurate and secure ligation as well as providing the beneficial effects of periarterial sympathectomy to the extremity. When ligation of a major artery is required, the companion vein should be ligated as well, since this decreases the likelihood of gangrene.
3. If the artery has not been opened, but is contused, and thrombosis has taken place, it should be ligated and divided, and the exposed, thrombosed portion excised, and the same procedure performed on the companion vein.
4. When approach to the artery through the wound appears too difficult, expose the artery believed to have been injured so far proximal to the point of injury as to secure a clean, dry field. For temporary arrest of the hemorrhage, pass a small rubber tubing or tape around the vessel.
5. A pulsating hematoma increasing in size and progressively interfering with the circulation of the extremity distal to the hematoma, requires surgical intervention.
6. Cases of arteriovenous fistulas are rarely detected in the first day or two after wounding. They are not per se an indication for operation and are better left until a later date unless there is a complication, such as leakage or deterioration of the arterial supply to the limb.
7. Supportive treatment for the patient in whom there is anxiety about the circulation to a limb should be as follows:
 - a. Heat the individual's body and the root of the injured limb, protect the limb from heat loss by woolen coverings, if possible, but never heat the injured limb itself.
 - b. Perform paravertebral novocain block, if feasible, to overcome spasm of the collateral blood supply. This procedure to be repeated every 12 to 24 hours if a beneficial response is obtained.
 - c. If gangrene threatens, keep limb wrapped in sterile towel and observe closely for the possible development of gas gangrene.

MEDICOMILITARY PROBLEMS IN TREATMENT OF ACUTE ARTERIAL INJURIES

Any discussion of the therapy of vascular injuries must begin with the premise that the restoration of the flow of blood through the original channel is the desideratum. Unfortunately, even in civilian practice this can be accomplished in only a limited number of cases, while in military surgery, for a variety of reasons, this number is still more limited. These reasons, which have been present in all the wars of history, may be divided into two categories: Those in which the factors are of such vital significance that they seal the fate of the limb regardless of the form of therapy; and those which jeopardize the effects of ideal therapy or preclude its institution.

²⁴ See footnote 23, p. 71.

Time Lag

The first factor which influenced the outcome in vascular injuries in World War II, as in previous wars, was the time lag between wounding and surgery. Therapy, designed to reestablish the circulation of the limb, must be carried out within a limited period after wounding. This limit was generally (if arbitrarily) set at 6 to 8 hours. While this criterion can usually be observed in civilian practice, in military surgery it is frequently impossible because the circumstances of combat often do not permit prompt rescue and treatment. In a sample group of 104 first-priority patients studied in the Mediterranean theater, the time lapse from wounding to arrival at a field hospital ranged from 1 to 34½ hours and averaged about 12½ hours. The time lag between wounding and tagging (first aid) ranged from a few minutes to 25 hours and averaged about 5 hours. The time lag from arrival in the hospital to operation ranged from 1 to 10¾ hours and averaged about 3¾ hours. This delay was caused chiefly by the necessity for resuscitation before surgery. In a sample of 58 casualties with vascular injuries from the same theater, the time lag between wounding and surgical treatment averaged about 15 hours, which is almost twice the maximum period for safe arterial repair. After such a length of time, regardless of the nature of the original wound, thrombosis had usually occurred in the vascular tree distal to the injury and the tissues of the wounded extremity had been deprived of oxygen and nutrition too long for the changes to be reversible.

From the military standpoint, it is doubtful that the time lag between wounding and treatment can be reduced much lower than it was in World War II. As the figures just cited show, nearly half of it was taken up by the period between wounding and first aid and was therefore a strictly military consideration. Furthermore, while in World War II every effort was made to bring expert surgical care as near the frontlines as possible, it was impractical to institute it at the level of the battalion aid station.

The establishment of vascular wounds as a special category, to be handled by a special routine, was also not feasible.²⁵ For one thing, vascular injuries, in spite of their seriousness, constituted such a small proportion of the total wounded that the imposition of another special category on the already overburdened military organization could not have been justified. For another, the effective operation of such a classification would have required of medical corpsmen a degree of differential diagnostic skill which they could not be expected to possess.

To preserve the circulation in the affected limb until patients with vascular injuries could reach installations at which specialized treatment was available numerous methods were suggested. Most of the suggestions were made by physicians and surgeons without experience in the hard facts of military surgery and were not practical. Certain advocates of refrigeration, for instance,

²⁵ Odom, C. B.: Causes of amputations in battle casualties with emphasis on vascular injuries. *Surgery* 19: 562-569, Apr 1946.

proposed its use under combat conditions. Aside from other considerations, discussed later in the chapter, this method was completely impractical for the battlefield.

The use of anticoagulant therapy (heparin) before the patient reached a hospital installation with laboratory facilities was also impractical. This form of therapy can never be employed with safety unless the patient is under constant observation and in an installation where repeated determinations of the clotting time of the blood can be made.

The same charges of impracticability, though perhaps to a somewhat lesser degree, can be made against sympathectomy and even sympathetic block. Installations on the level of a field hospital are not designed for such purposes and the performance of these operations in them can not be justified in any but occasional cases.

In view of these various factors, there was little to do but make the best of the situation and to keep the time lag between wounding and treatment as low as the military circumstances permitted. Admittedly if this lag could have been reduced much better results could have been obtained. The importance of the time factor can best be revealed by an analysis of 473 cases from the American material, in 207 of which amputation had to be performed (Chart 7). Only a negligible number of the casualties in the 1- to 10-hour group were seen much earlier than 10 hours, which explains why the results in that category are not much better than the results in the whole group. When debridement had to be delayed overlong the limb was often lost because of anaerobic infection, though it is doubtful that this cause explained many of the cases in the 1- to 10-hour group. It played an increasingly important role, however, as time progressed, and it probably accounted, at least in part, for the unhappy results in the group observed 20 hours or more after wounding. On the other hand, from the standpoint of possible reestablishment of the circulation, it is questionable whether a time lag of more than 10 hours was of special significance, since, as already pointed out, corrective measures must be instituted well within the upper limits of this period if good results are to be secured.

Practical Difficulties

Reparative vascular surgery is always difficult surgery. It is time consuming, it requires special and delicate equipment, and it must be performed by a surgeon of highly specialized experience and great technical dexterity.²⁶ When casualties reached battalion aid stations they were usually observed by nonspecialized medical personnel or, occasionally, by military administrative officers. Men assigned to these stations were neither trained nor equipped to institute specialized treatment. Even at field hospitals casualties were not usually seen by experienced vascular surgeons. The infrequency of vascular injuries would not have warranted the assignment of the limited number of

²⁶ De Takats, G.: Vascular surgery in the war. War Med. 3: 291-296, Mar 1943.

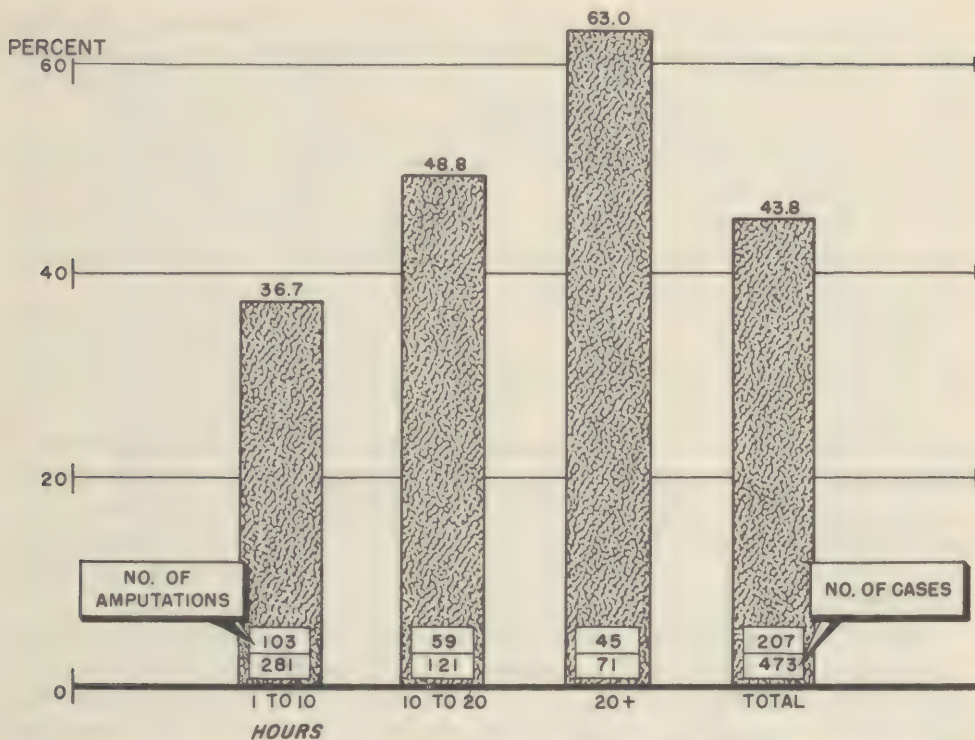


Chart 7. Effect of time lag between wounding and operation on incidence of amputation in arterial wounds of the extremities among American battle casualties in World War II. The data depicted are based on a selected group for which the necessary information was available. They do not include all arterial wounds during World War II.

medical officers in this group to installations on this level. Finally, when casualties with vascular injuries did reach installations at which definitive surgery could be done, the ablest surgeons, as already intimated, were working against factors which were beyond their control and under conditions which had usually ceased to be favorable. Outstanding results could not, therefore, be expected.

Status of the Casualty

In addition to such external factors as the time lag and the lack of experienced vascular surgeons in forward areas, certain other factors inherent in this type of injury precluded generally good results. One was the predominant necessity of saving the casualty's life before any endeavor was made to save his limb. Even when the vascular injury was the only injury, the patient was often in such poor condition from exposure, loss of blood, and other causes when he reached the hospital that operation had to be postponed until he had been sufficiently resuscitated to withstand it.

An important consideration in this connection was the amount of blood lost. In the majority of vascular wounds considerable loss occurred before first aid could be instituted. A sample group of 27 patients studied during the first week after wounding was found to have an average erythrocyte count of only 2,700,000 per cubic millimeter. The hemoglobin concentration in 24 of the 27 patients was still only 60 percent of normal, though all of the patients had been given whole blood in amounts which were thought to be adequate. One patient in the group, with a wound of the femoral artery, had lost 40 percent of his normal blood volume when first seen.

Naturally, if the volume of circulating blood was reduced, the amount which passed through the peripheral arteries was also reduced and the circulation in the distal portion of the extremity in which a vascular injury had occurred was still further curtailed and nutrition of the limb suffered accordingly. From both the systemic and local standpoints prompt restoration of the circulating blood volume and hemoglobin concentration was essential. In fact, the patient with a wound of the extremity often required as much blood, and sometimes even more blood, than one with a wound of the chest or abdomen.

Associated Wounds

Another consideration which contributed to the seriousness of vascular injuries was the presence of associated wounds which were often extremely serious. In not more than a third of all cases was the vascular wound the only wound. Associated wounds of the abdomen, chest, or head sometimes required attention far more urgently, as a lifesaving matter, than did the vascular wound, and vascular surgery had to be deferred in their favor. Other local wounds might further impair, or altogether destroy, the regional circulation and make salvage of the limb entirely impractical. Compound fractures, for instance, frequently tore collateral vessels and favored the development of inflammation and thrombosis. Patients were seen in whom plaster casts were not adequately padded under the distal fragment of a fracture of the lower third of the femur. Damage to the femoral and popliteal arteries resulted, and these cases almost invariably terminated in gangrene.

The series of vascular injuries which form the basis of this chapter show how seriously the presence of associated fractures affected the outcome of such injuries (Chart 8). The incidence of amputation was significantly higher when the vascular injury was complicated by a fracture. The observation is significant in itself and also suggests the importance, when studied in connection with the British figures, of analyzing all the circumstances in any given series of cases before drawing conclusions from comparative studies.

Nerve injuries were frequently associated with vascular injuries, as they naturally would be, since with few exceptions all large blood vessels are accompanied by peripheral nerve trunks. This is especially true of the neck, and of the brachial, femoral, and popliteal regions. The sciatic nerve was likely to be involved in traversing wounds of the thigh, and the peroneal and tibial

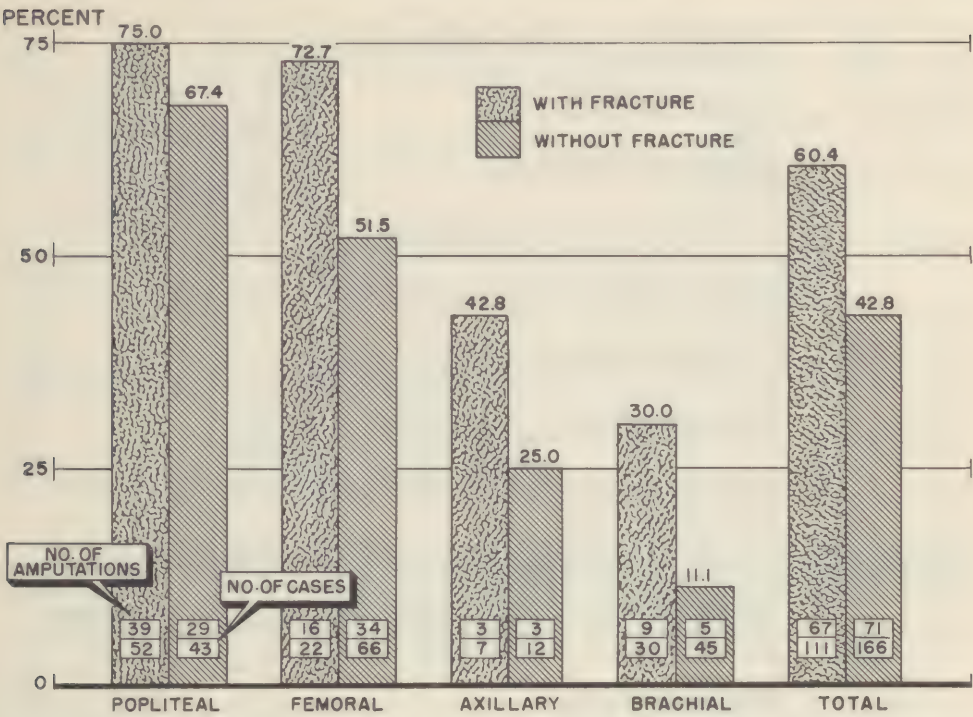


Chart 8. Effect of presence or absence of associated fractures on incidence of amputation in arterial wounds of the extremities among American battle casualties in World War II. The data depicted are based on a selected group for which the necessary information was available. They do not include all arterial wounds during World War II.

components in large open wounds of the popliteal space. Nerve injuries often had a large share of the responsibility for the permanent disability which followed some vascular wounds, but occasionally, and paradoxically, they exerted a transient beneficial effect in that they produced vasodilatation peripherally in the area supplied by the affected nerve.

Site and Type of Injury

On the basis of actual experience of surgeons in the field, and under the conditions and limitations imposed by military practice, the categorical statement can be made that the site and type of a vascular wound determine the therapeutic procedure and therefore predetermine, so to speak, the end results. The British experience in World War I, whenever detailed statistics are available for analysis (Chart 9), bear out this generalization. It is also borne out by the American experience in World War II (Chart 9). Almost invariably it could be anticipated that wounds of certain vessels, such as the popliteal artery, were much more likely to be followed by ischemic gangrene than were those of certain other vessels, such as the brachial artery. Indeed, for practical pur-

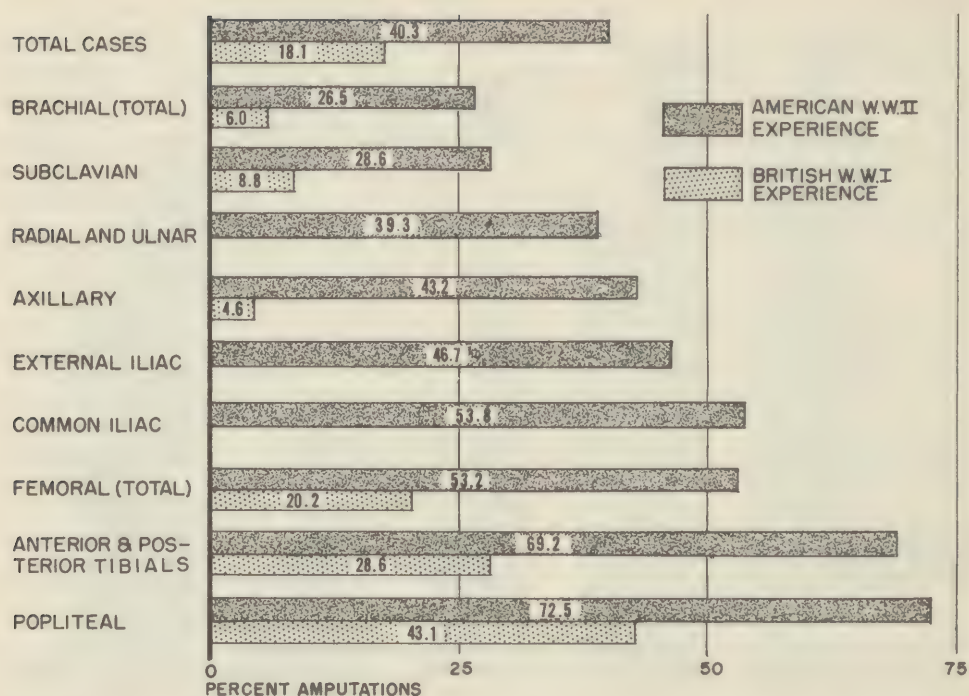


Chart 9. Effect of site of arterial wounds of the extremities on incidence of amputation in American battle casualties in World War II and in British battle casualties in World War I. The data depicted are based on a selected group for which the necessary information was available and are not to be considered as complete. See text, pp. 63-65, for details of selectivity.

poses it was quite possible to make up categories of critical and noncritical arteries. This observation held, however, only for single wounds. In the material studied, a wound of either the anterior or the posterior tibial artery was relatively noncritical, but when both arteries were damaged the injuries resulted in the second highest proportion of gangrene in both the British and the American material.

Generally speaking, wounds of the lower extremity were more serious than those of the upper extremity (Chart 10).²⁷ The incidence of amputation was considerably greater in wounds of the lower extremity, from the iliac through the popliteal arteries, than in those of the upper extremity, from the subclavian through the brachial arteries. Other considerations also entered into the amputation rate. In injuries of the brachial and femoral arteries, for instance, it made a difference whether the injury was above or below the profunda branch (Chart 11).

²⁷ The figure 2,453 is used instead of 2,471 as shown in Table 3, because included in the latter are 18 cases: aorta, 3; carotid, 10; external carotid, 3; and renal, 2.

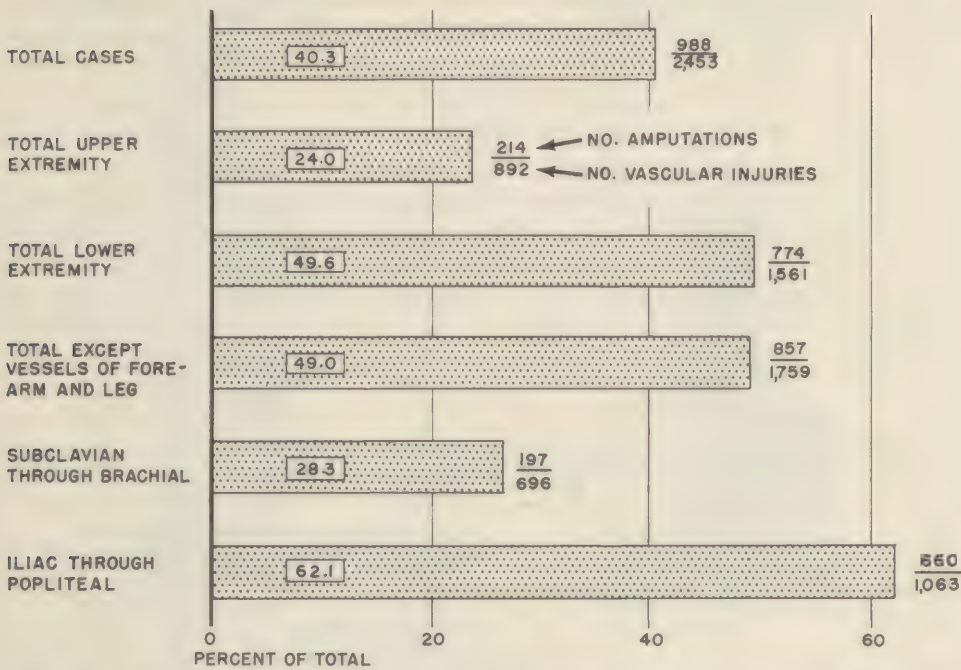


Chart 10. Effect of site of arterial wounds of the extremities on incidence of amputation in American battle casualties in World War II. The data depicted are based on a selected group for which the necessary information was available. They do not include all arterial wounds during World War II.

The role of special vessels in producing the end results of traumatic vascular surgery can be arrived at in another way. If the injuries of single vessels in the forearm and leg (the radial, ulnar, anterior and posterior tibial, and peroneal arteries) are excluded from the 2,453 arterial wounds of the extremities (see footnote 27, p. 78) collected from American armies in various theaters of operations (Table 3), the incidence of amputation after vascular injury rises to 49.6 percent. If only multiple arterial wounds of the leg and wounds of the iliac, femoral, and popliteal arteries are considered, the incidence of amputation rises to 62.6 percent (Table 3). A similar selective analysis of the British material reveals comparable conditions.

What these figures show is this: In any unselected group of vascular injuries the proportion of poor results will be high or low according to the number of important or unimportant vessels involved. All recorded military experience is to this effect. The most common reason for the poor results of vascular surgery in World War II was that the surgeon, no matter how great his skill, had no factor of choice, and therefore no responsibility in regard to the site of the wound. He had to institute therapy in accordance with its location, and

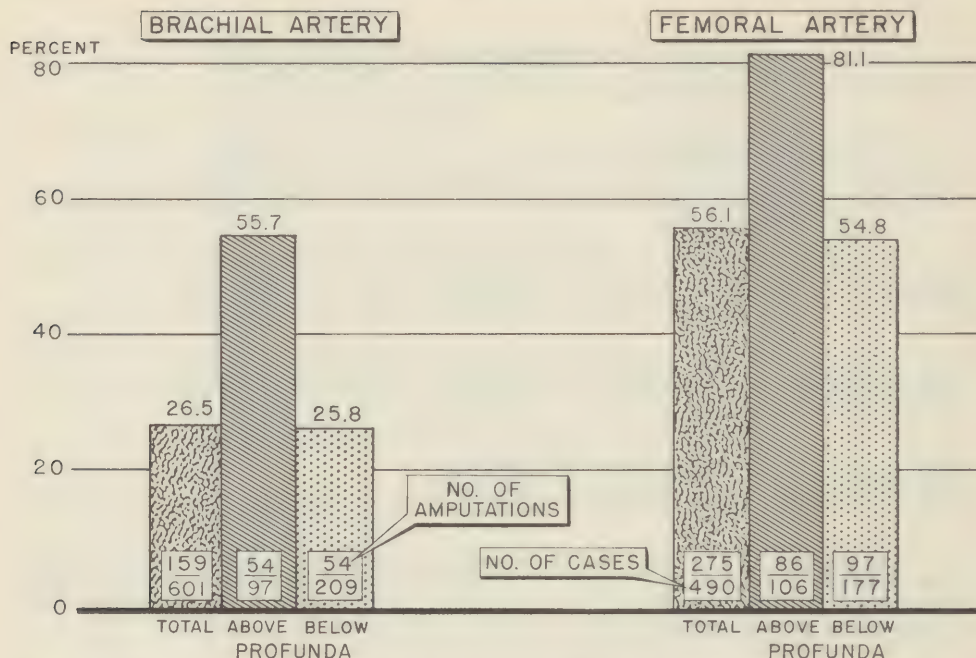


Chart 11... Effect of site of wounds of the brachial and femoral arteries on incidences of amputation in American battle casualties in World War II. The data depicted are based on a selected group for which the necessary information was available. They do not include all arterial wounds during World War II. The 27 cases involving the profunda femoris shown in Table 3 have been excluded as not pertinent to this consideration.

its location was the determining factor in whether or not the limb could be saved.

The extent of the arterial wound also played a part in the end results. Generally speaking, the larger the injury, (1) the greater was the chance that the collateral circulation was also damaged, (2) the more extensive was the necessary debridement, and (3) the greater was the chance of infection if debridement was not adequate.

The actual type of injury was another factor of dominant importance in determining the end results of arterial injury. Although in the American material from World War II it was possible from the records to separate only 620 of the 2,453 cases into distinct categories on this basis (Chart 12), the incidence of amputation seemed definitely related to the type of lesion. The figures merely corroborate the clinical opinions of the surgeons who handled these patients.

In those injuries in which thrombosis occurred, since this type of lesion was always likely to cause widespread interference with the flow of blood through collateral vessels, the worst results ensued, as might have been expected. Circular Letter No. 178, dated 23 October 1943, from the Office

of The Surgeon General,²⁸ recommended that thrombotic segments of damaged vessels be excised, not ligated, and later directives²⁹ from the Surgeon General's Office and other theaters of operations gave the same instructions.

Arterial lacerations usually represented a serious type of injury. Minor lateral lacerations, in which conservative surgery was possible, were seldom encountered. In the present series (Chart 12) the category of lacerations and transections includes 200 lacerations, 253 transections, and a number of cases in which it could not be determined which of these lesions was present. In the latter group the incidence of amputation, as might be expected in view of its composition, was midway between the incidence of lacerations in which interference with the circulation might be limited and the incidence in transections in which there was abrupt interruption of the blood supply. Clean-cut

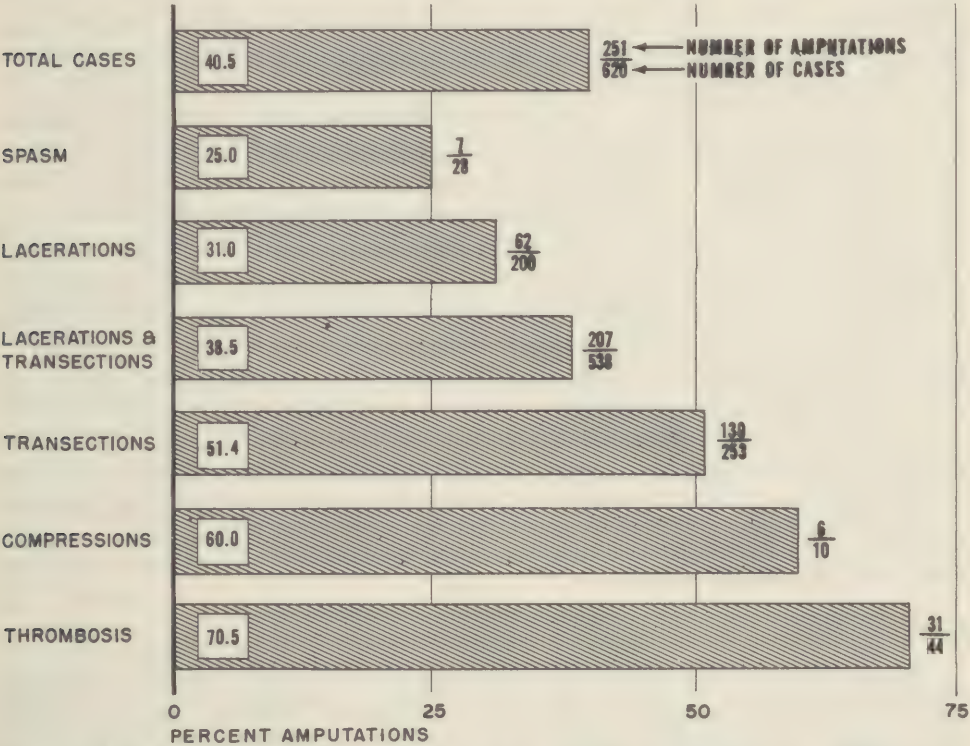


Chart 12. Effect of type of arterial wounds of the extremities on incidence of amputation in American battle casualties in World War II. The data depicted are based on a selected group for which the necessary information was available. They do not include all arterial wounds during World War II. The total number of lacerations and transections is greater than the sum of the individual lesions in this category because it could not be determined from 85 of the records which of these particular lesions was present.

²⁸ Cfr Ltr 178, SGO, 23 Oct 43, sub: Care of the wounded in theaters of operation.
²⁹ TB Med 147, Notes on care of battle casualties, Mar 1945.

transections were seldom observed. In most cases tearing of the tissues resulted in extensive loss of substance, usually associated with extensive damage to the collateral circulation.

The category of arterial compression (Chart 12) includes only a small number of cases (10), but its importance is indicated by the fact that in 6 of the 10 cases amputation was necessary. Experience showed that this was a very important group because compression injuries commonly occurred in association with fractures of the lower end of the femur with posterior displacement. No difficulties arose when the situation was corrected promptly. When it was not, the consequences were usually disastrous.

A category of injuries which does not appear in this classification because it could not be identified from the records, but which is known to have been observed in World War II, is the so-called concussion of the artery (*stupeur artérielle*).³⁰ This was a localized segmental type of spasm of the artery which followed various forms of trauma. A traumatizing agent which did not injure the artery itself but passed near the vessel, or even at some distance from it, was usually the cause. In such cases the limb was pale, cold, and pulseless, but there was nothing to suggest hemorrhage, hematoma formation, or other results of laceration. In differential diagnosis it had to be distinguished from thrombosis. The spasm which followed arterial concussion usually lasted only for some hours, but might last for many days (see Case 16). It was sometimes sufficiently intense and prolonged to result in death of the limb, though as a rule it responded well to debridement of adjacent lacerated tissues, conservation of body heat, or sympathetic block. The latter procedure, to be successful, had to be accomplished as soon as practicable after the diagnosis was made. If it did not achieve the desired results, then sympathectomy was performed.

In one case of arterial concussion observed in the Mediterranean theater, a shell fragment produced wounds of entrance and exit on the lateral aspect of the right calf at the midpoint. Although exploration revealed the track of the missile to be between 6 and 8 cm. from the posterior tibial artery, this vessel was in complete spasm.

Infection

In World War II infection was perhaps the least important of the limitations on therapy imposed by the circumstances of warfare. Battle wounds were always potentially infected, it is true, but when adequate debridement was carried out surgical procedures directed toward the treatment of the vascular injury could be done at the same time with a high degree of safety. It was not infection but other circumstances (time lag and type and location of wound) which prevented reparative procedures in most battle injuries of the blood vessels. The majority of the wounds in World War II were produced by shell fragments; many of them were of considerable size, were associated

³⁰ See footnotes 22 (3), p. 70; 28 and 29, p. 81.

with extensive destruction of tissue, and were not favorably located (Charts 9, 10, 11). As a result, the vitality of the limb was usually gravely impaired before the surgeon ever saw the patient.

RESULTS OF ACUTE OCCLUSION

The results of acute occlusion of the major arteries in combat-incurred wounds, whether caused by the injury itself or by ligation of the injured vessel, have not been clearly established.

Part of the confusion, as has already been intimated, lies in the statistics which for so many years were accepted as representing the incidence of gangrene after acute traumatic vascular occlusion. Actually they represented no such thing, since most of them included instances of aneurysm as well. The two lesions are, of course, totally dissimilar. In acute occlusion, whether produced by injury or ligation, the blood flow is cut off abruptly. In aneurysm the occlusion occurs gradually, if at all, and by the time it has developed or the aneurysm has been excised a more or less adequate collateral circulation exists.

Furthermore, in many series gangrene is the only unfavorable result reported. The percentage of cases in which primary amputation had to be done because of arterial injury is completely disregarded and such series therefore do not represent the incidence of poor results in acute traumatic arterial occlusion. As for the various series in which amputation is included—in popliteal arterial occlusion, for instance, it varies from 0 to 100 percent³¹—it is difficult to determine on what possible basis the calculations have been made.

Makins' statistics,³² which represent the largest collective experience in World War I, furnish an excellent example of the confusion which results from the inclusion of both acute and nonacute (aneurysmal) lesions in a single series. Actually, 49 percent of the cases in the series are aneurysms, and in such vessels as the axillary and subclavian arteries the proportion is more than 70 percent. When, so far as possible, the favorable influence of aneurysm is excluded, the proportion of poor results in Makins' series rises from 18.1 to 26.5 percent.

When Makins' figures are thus corrected, the American results in World War II, which at first glance seem much worse than those of the British in World War I, are probably better. The American series does not include aneurysms, the influence of which on statistics is always favorable, because, as the experience at the vascular centers in the Zone of Interior clearly showed, gangrene almost never occurs after operation for this type of lesion.

The confusion apparent in Makins' series is almost always evident in other reported series, e. g., Salomon,³³ and Soubotitch.³⁴ On the other hand, from

³¹ See footnotes 4 and 6, p. 61.

³² See footnotes 3, p. 60; and 12, p. 64.

³³ Salomon, R.: Beitrag zur Lehre der arteriovenösen Schussaneurysmen. *Beitr. z. klin. Chir.* 113: 369-410, 1918.

³⁴ Soubotitch, V.: Quelques considérations sur les anévrysmes traumatiques. *Bull. et mém. Soc. de chir. de Paris* 42: 698-708, 1916.

every series in which aneurysms are excluded, the proportion of amputation in vascular injuries is high. In 74 cases collected by Franz³⁵ from German World War I statistics the percentage of gangrene was 70.4 percent, and Mocquot and Fey³⁶ reported an amputation incidence of 44 percent in 61 vascular injuries observed in a French surgical ambulance.

The reported series which concern arterial ligation are no less confused than those which deal with acute vascular injuries in which ligation has not been done. From the period prior to World War I, no series large enough to be representative is available, but Sencert,³⁷ who collected a small number of cases, reported that the incidence of gangrene ranged from 5 percent when ligation of the subclavian and brachial arteries was done, to 50 percent when the common iliac artery was ligated. The author himself explained this remarkably wide range by the inclusion of aneurysms in the series.

On the basis of his personal military experience, Sencert³⁸ reported in 1918 that ischemic gangrene had occurred only twice in 70 cases of vascular injury in which ligature was done a few hours after injury and in which no hematoma of any significance was present. The figures, again, cannot be accepted at their face value because 4 cases are included in which the injury was venous, not arterial. When a diffuse hematoma had formed, the results were much less satisfactory; of 20 cases in which the axillary, femoral, and popliteal arteries were involved, gangrene developed in 6. The figures are perhaps somewhat selective because of Sencert's own pronounced views concerning the important role of hematoma formation in arterial injuries.

Amputation after arterial wounds in World War II was usually done for one of two reasons, gangrene or infection. The so-called toxic absorption, which is assumed to be the result of autolysis of muscle in the ischemic limb and which gives rise to systemic manifestations, should probably be classified as infectious in origin.

Among American troops in World War II, ischemic gangrene, not infection, was the chief reason for amputation after vascular injuries (Table 4). Even when clostridial myositis is combined with other infections it is seen that not more than a fifth of the amputations were performed because of infection. This is in decided contrast to what happened in some other armies. Turovets,³⁹ for instance, in an analysis of the 12 amputations required in 49 vascular injuries sustained in the Russo-Finnish War of 1939-1940, found that 10 of the 12 were for gas gangrene or other infection while only 2 were for ischemic gangrene.

³⁵ See footnote 17, p. 64.

³⁶ Mocquot, P., and Fey, B.: *Gravité des lésions artérielles du membre inférieur dans les plaies de guerre*. *Rev. de chir.* 53: 241-267, Mar-Apr 1917.

³⁷ Sencert, L.: *Le traitement des plaies vasculaires à l'avant*. *Lyon chir.* 14: 638-636, Jul-Aug 1917.

³⁸ Sencert, L.: *Wounds of the Vessels*. London, University of London Press, Ltd., 1918.

³⁹ Turovets, I. G.: Gunshot wounds of the blood vessels. *Khirurgia* No. 5-6, 1942, p. 35-46. *Abstr. Am. Rev. Soviet Med.* 1: 41, 1943, and *Bull. War Med.* 4: 628-629, Jul 1944.

TABLE 4. INDICATIONS FOR AMPUTATION IN 189 CASES OF VASCULAR INJURY ¹

Indication	1943		1944-45		Total 1943-45	
	Cases	Percent	Cases	Percent	Cases	Percent
Primary ²		0	43	32. 3	43	22. 8
Gangrene	47	84. 0	64	48. 1	111	58. 7
Clostridial myositis	8	14. 0	13	9. 8	21	11. 1
Other infections	1	2. 0	13	9. 8	14	7. 4
Total	56	100. 0	133	100. 0	189	100. 0

¹ Simeone, F. A.: Data from study of NATOUSA and MTOUSA proceedings of Disposition Boards for Amputees.
² These amputations were done at initial wound surgery, when vascular injury made survival of the limb unlikely.

There are other reasons, in addition to the inclusion of aneurysms in Makins' series, why the American results of arterial injuries in World War II seem worse than the British results in World War I. In 86 percent of the American cases the wounds involved important or critical arteries. This was true of only 70 percent of the British cases (Chart 6). The American figures, furthermore, include among the poor results all cases in which amputation was necessary after vascular injuries regardless of the cause. It is possible, though exact statements cannot be made on this point, that there are excluded from the British figures some cases of gangrene and amputation which were classified as infections rather than as vascular injuries, as well as those in which amputation was necessary for extensive trauma and other complications of vascular injuries. Finally, because of the more destructive weapons used in World War II, it may be assumed that tissue destruction was greater among American wounded in the Second World War than in the British cases of the First World War. As a result, in addition to the injury to the main arterial circulation, the collateral circulation was frequently and seriously impaired. Further, debridement, which was probably more commonly practiced in the Second World War than in the First, was more extensive. Debridement was, of course, an essential procedure. Its omission in cases of arterial injuries would undoubtedly have resulted in a higher mortality rate, as well as in the loss of more limbs from infection. When debridement is properly performed, however, it involves loss of tissue and in extensive wounds its thorough performance inevitably entails additional damage to the collateral circulation.

CONTROL OF HEMORRHAGE

Packs

In the control of hemorrhage, packs were avoided as far as possible. Generally speaking, seepage was less harmful than the damage resulting from their use, for gauze packs inserted to check bleeding inevitably became tight and when allowed to remain in place during a prolonged evacuation eventually

caused a good deal of damage. Quite properly, packs were used as a temporary expedient for controlling hemorrhage when they could predictably be removed within a few hours at a hospital installation. The use of a tourniquet was thereby avoided.

Tourniquets

Tourniquets surely saved the lives of many soldiers in World War II who otherwise would have died of hemorrhage. On the other hand, they were undoubtedly applied in some cases in which they were not really needed and were responsible for the loss of some limbs which could have been saved. In all theaters of operations surgical consultants and their assistants gave instruction in the correct use of the tourniquet, emphasizing when its use was and was not indicated, proper methods of application when its use was justified, and correct management of a casualty with a tourniquet in place. Only by careful evaluation of the patient's blood loss, state of shock, facilities available for blood volume replacement therapy, time interval likely to elapse before primary surgery could be done, and the extent of damage to an extremity, could a proper decision be made as to the application or removal of a tourniquet.

Intelligent handling of this life- and limb-saving device demanded that each casualty be treated as an individual problem. The application of a tourniquet for every wound of the extremity, with its release every half hour by rule of thumb, was always a potentially dangerous method.

Observations on the correct use of the tourniquet were best made in forward installations, chiefly in field hospital units, which accepted extremity wounds in which hemorrhage was a factor. It was in these units that most patients who had had tourniquets applied were seen and it was therefore in these units that most of their life-saving and life-endangering results could be observed. The following observations on tourniquets are based on the conclusions reached concerning them by Maj. Luther H. Wolff and Capt. Trogler F. Adkins,⁴⁰ who were attached to the 2d Auxiliary Surgical Group. This team operated for more than a year in one of the "first priority" surgical hospitals on the Italian front. It will be noted that certain of their data and conclusions are at variance with practices accepted as correct before World War II, though they are in agreement with the data and conclusions of most other surgeons who had similar frontline experiences.

Choice of Tourniquets. Because complete control of bleeding is the primary objective of tourniquet application, any result less than this must be considered inadequate. For that reason the strap-and-buckle type of tourniquet issued by the Army and generally used early in the war was not a satisfactory piece of equipment for first aid on the battlefield: It was so narrow that it cut into the tissues, and it seldom controlled bleeding completely no matter how tightly it was applied. The failure of this piece of equipment to produce desired results

⁴⁰ Wolff, L. H., and Adkins, T. F.: Tourniquet problems in war injuries. Bull. U. S. Army M. Dept. 87: 77-84, Apr 1945.

could be explained in part by the usual practice of placing a gauze roll or some similar firm object over the affected vessel before it was applied. The vessel, being cordlike and elusive, frequently slipped out from under the roll and bleeding continued. If the principal vessel was successfully occluded the collateral blood supply parallel to it was not, since the pad so elevated the tourniquet on either side that no pressure was applied to the vessels on either side of the principal vessel. When the strap-and-buckle tourniquet was the only type supplied, better results were obtained by substituting mechanic's waste or a Carlisle dressing for the gauze pad, or by using no pad whatsoever.

The most satisfactory tourniquet was the pneumatic type in which the pressure could be accurately adjusted and maintained. This type, however, had two disadvantages: Pressure leakage was always a possibility, and it was too cumbersome and complicated for quick application on the field of battle. However, when circumstances permitted, the pneumatic tourniquet which records pressure in pounds per square inch or in millimeters of mercury was safer. One pound of pressure in the model supplied was equivalent to 51.7 mm. of mercury. When the tourniquet was applied to the arm, 5 pounds of pressure (250 mm. of mercury) was usually sufficient; in the leg the pressure seldom had to exceed 6 pounds (300 mm. of mercury).

The simplest and most effective type of tourniquet for frontline use was not a manufactured article but a $\frac{1}{2}$ -inch soft rubber tubing (U. S. Army Medical Supply Catalog Item No. 3879000) in 6-foot lengths. When this size was not available $\frac{3}{4}$ -inch rubber tubing (Item No. 3878000) was an acceptable substitute. Care had to be taken that only moderate tension was applied because complications which followed the use of rubber tubing were nearly always the result of too much tension.

Technique of Applying Rubber Tubing Tourniquet. The bleeding extremity was padded at the level at which the tubing was to be applied with a towel, shirt sleeve, trouser leg, or any similar available material. The tubing was then wound around the limb in 4 parallel turns under moderate tension only. The end first applied was overlapped and anchored by the second turn, and the last turn was anchored by the next-to-last turn. If the smaller-size tubing was used more turns were necessary—from 8 to 10 on the thigh, from 4 to 5 on the arm. It was most important that tension be moderate. If several turns were applied moderate tension was sufficient to occlude bleeding vessels completely and the dangers inherent in a tightly-applied tourniquet (a general fault) were thus avoided.

The tourniquet was placed about the thigh or upper arm as close to the site of injury as was feasible. If large defects were present care had to be taken to apply it sufficiently far above the injury to prevent its slipping down into the defect. Tourniquets placed about the forearm or leg were frequently not effective since bleeding from incompressible interosseous vessels was likely to continue and to lead to a considerable loss of blood.

Selection of Cases. Both judgment and experience were required to determine when a tourniquet should be applied and when it could be omitted safely. Many severe wounds of extremities, especially badly contused or avulsed wounds not involving major blood vessels, required no tourniquets. An inadequate tourniquet could actually increase bleeding from this type of wound. On the other hand, tourniquets were not used early enough and were insufficient in many serious extremity wounds involving large blood vessels or in patients with traumatic amputations. There may be some bias attached to this observation, since the only casualties admitted to hospitals on this level were those in shock or with tourniquets.

Statistical data are not available to show what proportion of casualties bled to death on the battlefield from wounds of the extremity, nor is it known how many died from hemorrhage after they had received first aid. No comments on this point would therefore be justified. It was common experience, however, to encounter in forward hospitals patients with wounds of the extremities to which tourniquets had not been applied and who survived the transportation. Although their wounds on gross inspection did not appear extensive, they had lost large volumes of blood. Studies of circulating blood volume and other data obtained from many such individuals often showed that they had lost from 33 to 50 percent, and sometimes more, of their circulating blood volume. This blood loss might have been avoided by proper use of the tourniquet.

It is true that when a wounded soldier reached the field hospital, usually within 6 to 8 hours after wounding, bleeding was likely to have stopped, but this did not always prevent his condition from being critical from loss of blood. Spontaneous arrest of hemorrhage took place as a physiologic process in many wounds of the extremity, but frequently it did not occur until the systolic pressure had fallen and sufficient spasm had developed in the vessel for natural processes to effect a cessation of the blood flow.

It was an essential precaution to apply a tourniquet to an extremity in which there had developed, or was developing, a large, pressure-producing hematoma as the result of injury to a major artery. Experience showed that more damage could be done to the limb as the result of the pressure and hemorrhagic infiltration caused by this type of lesion than by the application of a tourniquet for a reasonable time. It was highly unlikely that in such cases the collateral circulation present about the hematoma immediately after injury was sufficient to affect materially the viability of the distal tissues. It was also thought that the early application of a tourniquet increased the chances of firm, occlusive clotting. It was shown repeatedly that operation for the release of tension and for repair or ligation of the damaged artery was simpler, and clots and infiltrated blood could be handled more readily, if bleeding had not been permitted to progress unchecked.

That reliance on natural methods is a dangerous way to secure control of hemorrhage is shown by the following case:

Case 1. A sergeant was seen immediately after admission to a field hospital, 5 hours after a shell fragment had perforated the middle third of his left arm. No tourniquet had been applied. Although the initial blood pressure was 115 mm. of mercury systolic and 60 diastolic he was extremely pale, restless, and apprehensive and had obviously lost a large quantity of blood. The pulse rate (in the carotid artery) was 128 beats per minute. Generalized vasoconstriction was intense. Examination of the wound showed no bleeding at this time.

Within 10 minutes of admittance the patient's condition began to deteriorate rapidly, his blood pressure fell to 72 mm. of mercury systolic and 40 diastolic, and a transfusion of low-titer group O blood was started immediately. The blood was forced in under pressure, approximately 300 cc. being given in 15 minutes. In spite of the transfusion and other standard methods for the treatment of shock, the man died 25 minutes after he had been brought into the hospital.

A complete necropsy revealed his only wound to be a perforating one of the middle third of the left arm, which had caused a transection of the brachial artery and a compound comminuted fracture of the left humerus. The arterial wound showed no evidence of intraluminal clotting. The patient had had no signs of symptoms of fat embolism before death and no signs of this process were observed at necropsy. The cause of death was recorded as hemorrhagic shock.

Comment. The details of the circumstances preceding the admittance of this patient to the field hospital could not be obtained, and there are a variety of possible reasons why no tourniquet had been applied. Whatever they may be, the statement is believed warranted that had a tourniquet been applied in this case, death from blood loss would probably not have occurred. As this case, and numerous others, showed, an adequate tourniquet should be applied proximal to any wound of the extremity which is bleeding freely. It should be applied, moreover, at the earliest possible moment. Many of the fears of damage from tourniquets are probably unfounded to a large extent, and certainly the saving of every possible ounce of blood is the more important consideration from the standpoint of the patient's general condition.

Release and Removal of the Tourniquet. It is unfortunately true that in World War II some limbs were lost because tourniquets were left in place too long and gangrene developed. There was some disagreement, however, over how long "too long" was. Wolff and Adkins' experience in Italy⁴¹ showed that a tourniquet could be left in place from 2 to 6 hours without clinically detectable damage depending on the temperature of the atmosphere and of the extremity. During the winter of 1943-44 they observed tourniquets which had been left on as long as 8 hours without apparent deleterious effects. Surgeons of an auxiliary surgical group performed amputations on approximately a thousand patients in a forward field hospital. These surgeons all observed extremities on which tourniquets had been left applied up to 4 hours, yet no cases of gangrene solely from a tourniquet were noted. In no case was there an unusual degree of edema, a slough of the skin edges, or any ischemia of the muscles which could be attributed solely to the use of the tourniquet. Moreover, during the period of observation which lasted from 5 to 10 days in most

⁴¹ See footnote 40, p. 86.

cases, no instance was observed in which the application of a tourniquet had caused either nerve injury or thrombosis.

About the development of gas bacillus infection it is necessary to be less positive. This type of infection was observed in patients who had worn tourniquets for various periods of time, but it was also observed in others who had not worn them. Gas bacillus infection seemed somewhat more prone to occur in the bloodless extremity to which a tourniquet had been applied, but no definite opinion was formed on this point. It was the consensus, however, that even if these complications did occur more frequently, the role of the tourniquet as a lifesaving measure would still make its use imperative.

There are cases in which the removal or loosening of a tourniquet is unwise and unnecessary; in fact, the results may be disastrous. Experience has led to the conclusion that under no circumstances should a tourniquet be loosened on a patient in shock or in incipient shock unless means are present and immediately available to control any hemorrhage that may occur and to replace rapidly the volume of circulating blood. The presence of a medical officer was considered necessary. The following case histories illustrate the wisdom of these precautions.

Case 2. An officer was admitted to a field hospital 3 hours after he had been wounded by a shell fragment which traversed the right arm and produced a compound comminuted fracture of the humerus. This was his only wound. When he was admitted to the field hospital he was in mild to moderate shock. The blood pressure was 110 mm. of mercury systolic and 66 diastolic and the pulse rate was 112 beats per minute. The blood vessels were in a state of vasoconstriction. Although he had obviously lost considerable blood his condition was recorded as fair.

Examination of the wounded arm showed an improvised splint, a tourniquet of the strap-and-buckle type applied tightly at the level of the insertion of the deltoid muscle, and a fairly extensive perforating wound of the inner aspect of the lower arm. A slight but persistent oozing from the wound was thought to be of venous origin, the result of back stasis from a nonocclusive tourniquet. The tourniquet was therefore loosened and slipped off after a blood pressure cuff had been placed about the arm above it. Before the cuff could be tightened, the severed brachial artery broke away and in the few seconds required to pump up the blood pressure cuff enough blood was lost (not more than 100 cc.) to cause a drop in the blood pressure from 110 mm. of mercury systolic and 66 diastolic to 80 systolic and 40 diastolic and to deepen materially the state of shock. It is not hard to imagine what might have happened, since the circulatory volume was at a critical level, if measures for the prompt control of hemorrhage had not been available. The patient was immediately given 2,000 cc. of whole blood and after resuscitation had been accomplished a successful operation was performed. Recovery was uneventful.

Case 3. A private was admitted to a field hospital 6 hours after he had sustained a traumatic amputation of the left leg, just below the knee, from a German "Schu" mine. He was in severe shock with a blood pressure of 86 mm. of mercury systolic and 56 diastolic, and a pulse rate of 116 beats per minute. Examination disclosed a persistent trickle of blood from the badly contused stump although there were two tightly placed strap-and-buckle tourniquets about the thigh. A tourniquet of soft rubber tubing was substituted for these tourniquets and bleeding was promptly controlled. Vigorous resuscitative measures were undertaken, including infusion of 2,000 cc. of whole blood. At the end of 3 hours, however, the patient was still in such poor condition that operation could not be considered.

Ordinarily a patient with a wound of this sort could be prepared for operation within an hour and one-half at the most; if he could not be, a gas bacillus infection or continued bleeding was the usual explanation. Examination of this man's wound showed that the dressings which had been applied over the stump after the original examination were saturated with blood and that a pool of blood had collected under his buttocks. Questioning disclosed that the tourniquet had been loosened by a ward attendant at 30-minute intervals ever since it had been applied, and as a result the patient had been losing as much blood by its periodic release as he was gaining by transfusion. The introduction of another 1,000 cc. of whole blood with the tourniquet tightly in place produced the desired results and rendered the patient a safe risk for surgery within a short time.

It was repeatedly observed in the course of World War II that patients who had lost small to moderate amounts of blood could tolerate further rapid loss of small additional amounts without placing their chances of recovery in jeopardy. It was also repeatedly observed that many patients who had lost blood up to the critical level could maintain a semblance of circulatory equilibrium only by intense vasoconstriction, rapid heart action, and other physiologic compensatory mechanisms. It was in these patients that urgent care had to be used to prevent any additional decrease in blood volume. The rapid loss of even 100 cc. of blood could completely break down the delicately balanced compensatory mechanism and result in profound and often fatal shock through failure of the vasoconstrictor apparatus. It was never safe to loosen a tourniquet in such cases, no matter how long it had been applied, until the blood volume had been restored to a safe level by plasma transfusions or, better, by whole blood transfusions.

It also had to be borne in mind that patients may lose more blood than is first apparent on loosening a tourniquet, particularly a tourniquet about the thigh. The arterial system fills up more or less uniformly on release of a tourniquet, and if the vascular injury is some distance below the tourniquet the injured area continues to drain off the blood in the intervening vessels, even though the tourniquet is promptly reapplied upon the first sign of hemorrhage.

Principles of Tourniquet-Application. On the basis of observations made in the early months of the war, the following ideal plan was substituted for the former plan of releasing a tourniquet every 20 to 30 minutes:

1. An adequate tourniquet should be placed on an actively bleeding extremity at the earliest possible moment after injury.
2. A patient with a tourniquet in situ should be given the highest priority for transportation to the nearest available hospital and the presence of the tourniquet should be plainly indicated on his record.
3. At the end of 2 hours, providing the patient is not in shock and depending on the circumstances of the temperature and tactical situation, the tourniquet should be cautiously loosened under the supervision of a medical officer. The precaution of professional supervision should be omitted only in very exceptional circumstances. If bleeding recurs, the tourniquet should be reapplied at once. If hemorrhage apparently has been controlled, the tourni-

quet should be removed, but it should be kept available for instant reapplication and the patient should be kept under constant observation.

4. If a patient is in shock from hemorrhage, the tourniquet should on no account be removed within the first 4 to 6 hours of its application unless the blood volume has been at least partially replaced by plasma or whole blood. This plan involves a calculated risk, but the possible loss of a few inches of a badly damaged extremity cannot be permitted to compromise a patient's life.

5. At the end of the 4- to 6-hour period, removal or loosening of the tourniquet should be a matter of individual judgment on the part of the medical officer. After 8 to 10 hours have passed, it should be removed for it can be assumed that sufficient spasm and clotting have developed to prevent further bleeding. Even when the extremity is chilled, it is unwise to leave the tourniquet in place longer.

6. The temperature of an extremity about which a tourniquet has been applied should be lowered as far as possible, short of actual freezing.

Numerous experimental observations have shown that the temperature of a bloodless extremity has much to do with the speed with which tissue necrosis occurs, and that the metabolic demands of the tissues vary directly with the temperature. This observation was of importance in tourniquet application. A tourniquet applied in the heat of the tropics, or in the desert, had to be loosened at shorter intervals than a tourniquet applied in a cool or cold climate. While care was taken to prevent frostbite and other cold injuries in cold and freezing weather, it was the rule to leave uncovered an extremity about which a tourniquet had been applied, and never to employ artificial means to warm it.

EXPECTANT TREATMENT

The salvage of limbs which were the site of vascular injuries depended quite as much upon a multitude of details as upon the major surgical method used. Careful wound debridement minimized the chances of infection, as did chemotherapy and antibiotic therapy. Every possible collateral vessel was spared. Such circulation as was present was maintained by proper posturing and by the correction of oligemia and anemia. Circulation through the collateral channels was encouraged by the release of the vessels from vasoconstricting influences by means of sympathetic block or sympathectomy. Heparin was employed when circumstances permitted the proper precautions, to prevent thrombosis. No single one of these measures, all designed to improve the circulation, could guarantee survival of any limb, but the careful use of all of them, or of as many of them as possible, frequently made the difference between a good and a poor result.

Some surgeons felt that in a small and carefully selected group of vascular injuries either uncomplicated healing might take place without any surgery at all, or, if it did not, that aneurysm formation would take place. It is true that there is an almost negligible incidence of loss of limb after excision of aneurysms,

but it is also true that a traumatic arterial lesion is not necessarily followed by aneurysm formation. On the other hand, when it is possible to delay surgical ligation for a period of time, the status of the limb was frequently better than when it was necessary to perform it immediately.

Case 4. A soldier wounded by enemy shell fragments in Italy on 1 June 1944, at 1100 hours, incurred multiple penetrating wounds of the right hand, wrist, arm and chest wall, and of the right knee in the popliteal space where he sustained a through-and-through wound of the popliteal artery. He suffered no fractures in the lower extremity. All wounds were debrided in a forward hospital on 2 June between 2100 and 2135 hours, with the patient under thiopental sodium anesthesia.

On 6 June, en route in a hospital ship to a general hospital in the base, the patient complained of pain in the right knee and during ambulance transportation he bled from the wound in the popliteal space. Bleeding ceased spontaneously after loss of about a pint of blood.

He was taken promptly to the operating room where exploration revealed that the popliteal artery was enclosed in a sac which was pulsating strongly. The sac was not disturbed in the hope that an aneurysm would form. Since the wound looked clean, partial closure of the muscle was done. A firm dressing was applied down to the muscles and the leg was partially immobilized in a posterior plaster shell.

Roentgenograms the day after operation revealed a metallic foreign body 3 by 5 mm. in the right popliteal space. The total plasma protein concentration was 4.75 gm. per 100 cc. and the hematocrit value was 26.9 percent. By 9 June transfusions had amounted to 1,850 cc. of whole blood.

On 11 June the patient complained of pain in the right popliteal space and said he could "feel bleeding." Upon examination, no blood was apparent on the dressing. On 12 June he complained of more pain during the night. When the splint was removed both the dorsalis pedis and the posterior tibial arteries could be palpated on the right side, but pulsations were decidedly weaker than on the left side. The right foot was warm and well colored and sensation was intact. When the dressing was removed a fine-mesh gauze pack was found in place, and as it was loosened brisk bleeding developed. A firm pressure dressing was applied and the patient was taken to the operating room at once. There the pack was removed, the skin was closed with three interrupted sutures, and bleeding was controlled by a firm elastic bandage. A transfusion of 500 cc. of whole blood was given.

The following day the foot was warm. The patient could move his toes but he complained of pain in the right popliteal area radiating into the toes which were hypesthetic but not anesthetic. Recovery proceeded smoothly until 19 June, when there was a sudden hemorrhage from the right popliteal space. A pressure dressing was reapplied. The foot was warm and motion in the toes was normal. On 20 June, the total plasma protein concentration was 6.5 gm. per 100 cc. and the hematocrit value was 33 percent.

Bleeding recurred 23 June and was again controlled by a pressure dressing. Two days later the toes were still warm and there was less complaint of pain. On this day, however, there was another episode of bleeding which required the application of a tourniquet as well as of a pressure dressing. The total plasma protein concentration was 5.8 gm. per 100 cc. and the hematocrit value was 35.5 percent. On 26 June a right lumbar gangliectomy, with excision of the second, third, and fourth lumbar ganglia, was done with the aid of spinal analgesia.

On 27 June, the right popliteal artery was explored with the patient under ether anesthesia. After removal of a large organized clot with a pseudosac from the popliteal space, a through-and-through wound of the artery was found (Fig. 4). After the artery was

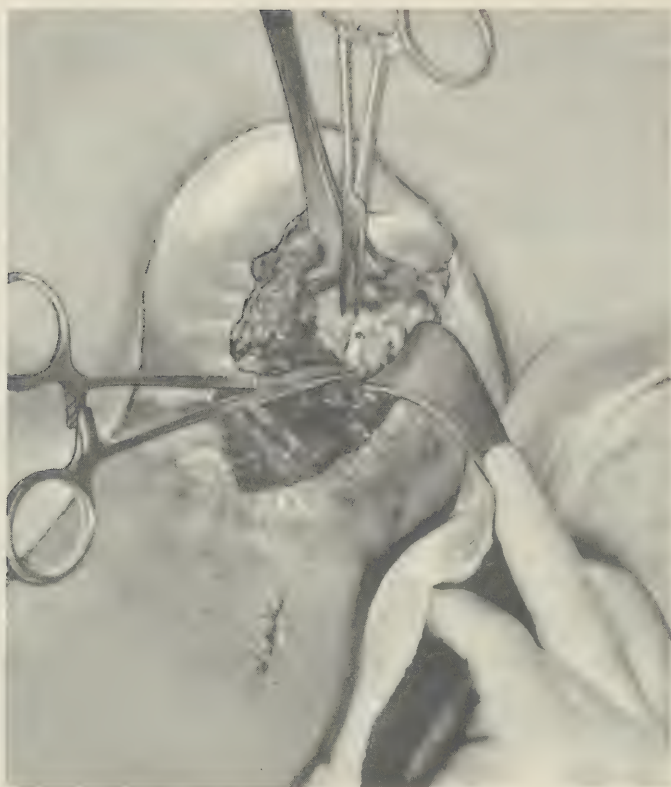


Figure 4. (Case 4.) Through-and-through wound of popliteal artery. Partially excised wall of hematoma is being retracted.

freed it was evident that suture of the injured vessel was not possible. The artery was therefore ligated above and below the injuries with No. 1 chromic catgut, the damaged segment (about 1.5 inches) was excised, and the foreign body removed. The segment which was excised lay between the outlet of the adductor canal and the middle geniculate artery. The vein was not thrombosed and was not ligated. Five hundred cubic centimeters of blood were given in the course of the operation and 500 more after operation.

Before the operation the right foot was definitely warmer than the left, but on palpation neither the dorsalis pedis nor the posterior tibial artery was palpable. Motion and sensation were normal except for mild hypesthesia to pin prick in the toes. The day after operation the right foot was colder and dryer than the left foot. Motion continued to be normal in the foot and toes. No pulsations were palpable in the right posterior tibial and dorsalis pedis arteries. Thereafter recovery was smooth, and by 30 June there was every indication that the injured extremity would survive. By 7 July when the patient was evacuated, the temperature of both feet was the same. The popliteal wound was well healed. The right calf was very slightly larger than the left, but no induration was palpable.

Comment. There are a number of lessons to be derived from this case. One is that it is possible for pulsation to be present in the dorsalis pedis and posterior tibial arteries even when there is a through-and-through wound of

the popliteal artery. Another is the advantage of delayed ligation of an injured artery. This patient would almost certainly have lost his leg if the popliteal artery had been ligated immediately after injury. On the other hand, this case clearly shows that evacuation of a patient with a wound of this character is hazardous. Early evacuation was permitted in this case because the wound was not recognized. Had it been recognized, and had expectant treatment been deliberately instituted in order to delay ligation of the artery, the patient would have been kept under continuous observation until the vessel had been ligated or the wound had healed, and the repeated hemorrhages could probably have been avoided.

Conservative therapy of vascular wounds was advocated as a deliberate policy by some British surgeons at the Congress of Central Mediterranean Forces Army Surgeons held in Rome in February 1945,⁴² but only a few American casualties were deliberately treated in this manner. Sandzen and Evans⁴³ treated 3 cases conservatively with excellent results in a series of 89 vascular wounds, 64 of which involved major arteries, and Rose, Hess, and Welch⁴⁴ treated 8 of 100 cases conservatively, also with good results. In 4 of the 8 cases the wounded vessels were exposed during debridement, but in the other 4 cases, in all of which the popliteal artery had been injured, they were not visualized.

The selection of cases for conservative management required expert surgical judgment, as well as a good deal of courage. The chief objection to the method was that it usually implied the omission of debridement which was so essential a part of the management of all war wounds that exceptions to its routine performance had to be made with the greatest caution. An additional reason for carrying out complete debridement in any case was that it afforded an opportunity to repair a laceration by suture or to perform nonsuture anastomosis. If the artery was intact its continuity could be determined without dislodging it entirely from its bed. Generally speaking, it was best to explore even trivial wounds with the idea of performing remedial or reparative surgery if there was evidence of complete interruption of the circulation. The following case histories point out the advantages of exploration:

Case 5. A soldier wounded by enemy shell fragments 20 May 1944 suffered a 2-cm. penetrating wound of the lateral aspect of the right knee with a laceration of the popliteal artery just below the geniculate branches. Only a quarter of the anterior arterial wall remained intact. Examination in a forward hospital revealed the popliteal area and calf to be tense and swollen. The right leg and foot were cold and motionless. No pulsations could be felt in the popliteal, dorsalis pedis, or posterior tibial vessels.

⁴² (1) Brown, J. J. M.: A plea for conservatism in the primary surgery of wounds of the main arteries of the limbs. *Proc. Cong. C. M. F. Army Surgeons, Rome, 12-19 Feb 45*, p. 103-106. Also discussions by Major Robb and Major Cleland.

(2) Erasmus, J. F. P.: The problem of wound excision in the treatment of vascular injuries. *Proc. Cong. C. M. F. Army Surgeons, Rome, 12-19 Feb 45*, p. 112-113.

⁴³ Personal communication to F. A. Simeone from S. C. Sandzen and B. H. Evans.

⁴⁴ Rose, C. A.; Hess, O. W., and Welch, C. S.: Vascular injuries of the extremities in battle casualties. *Ann. Surg.* 123: 161-179, Feb 1946.

The patient was operated upon 7 hours after wounding. The arterial laceration was sutured after removal of a large hematoma and the deep fascia over the upper half of the swollen calf muscles was incised. The right lumbar sympathetic trunk was blocked with procaine hydrochloride. The right thigh and leg were enclosed in plaster with the knee flexed to 30 degrees. No pulsations were felt in the posterior tibial and dorsalis pedis arteries at the end of the operation.

The following day the ankle and dorsum of the right foot were warmer though the toes remained cold and blanched. No pulse was palpable in the foot. Right lumbar sympathectomy was done with no obvious immediate improvement. Two days after operation the right foot and toes were warmer and there was partial return of sensation and motion. No pulse was palpable in the foot. Thereafter improvement was continuous until the patient was evacuated to the base 11 days after injury. At this time, although pulsations had not returned in the dorsalis pedis or posterior tibial arteries, the circulation in the injured extremity appeared satisfactory.

Comment. The result achieved in this case would be good for any type of acute injury of the popliteal artery. Before operation the circulation in the extremity was apparently seriously impaired. The collateral vessels were intact, and it is impossible to be certain whether the improvement which began a day or two after operation could be attributed to the function of the sutured popliteal vessel or to the function of the collateral vessels which had been released from compression by removal of a constricting hematoma.

Case 6. A soldier was wounded by mine fragments 20 October 1944. He incurred a wound with its point of entrance just above the head of the left fibula; the wound of exit was on the posteromedial aspect of the left thigh at a level 6 cm. above the wound of entrance. The popliteal artery was severed below the geniculate branches. At the evacuation hospital the popliteal space and upper calf were found to be swollen and firm. The left foot was cold and pulseless and only slight motion was possible.

With the patient under endotracheal ether anesthesia, operation was performed 6 hours after wounding. A large hematoma was evacuated from the popliteal space. The retracted ends of the popliteal artery were identified and were approximated by slight traction and 30-degree flexion of the knee. Thrombi were removed from both ends of the severed vessel and an end-to-end anastomosis was done with interrupted sutures of fine silk. All wounds were debrided. A long leg plaster was applied with the knee in 30-degree flexion. The left lumbar sympathetic chain was blocked with procaine hydrochloride. At the conclusion of the operation the condition of the foot was unchanged.

The day following operation the foot was still cold and pulseless but motion in the toes had improved. Sympathetic block was repeated. On 22 October the foot and toes were warm and free, and motion was possible although the dorsalis pedis pulse was still not palpable. By 2 November, when the patient was evacuated to a general hospital, all the toes were warm and sensation and motion in the whole extremity were practically normal.

Comment. The result in this case, in which the location of the lesion was approximately the same as in the preceding case, is also good for a laceration of the popliteal artery. In both cases the location was the best possible for maintenance of function of the collateral vessels. Since, however, improvement in the foot was delayed for 2 days after operation, it is impossible to be certain whether the popliteal artery functioned after suture or whether the good result is to be attributed to an adequate collateral circulation.

Supplemental Therapeutic Measures

Posture. The position of an extremity in which the blood supply is embarrassed as the result of disease or injury has long been a controversial matter. Directives and circular letters issued for the care of arterial injuries reflected the conflicting opinions. Circular Letter No. 13, dated 15 May 1943,⁴⁵ included elevation of the part among the emergency measures for the control of hemorrhage, but advised that following ligation of a vessel the extremity should not be elevated but should be slightly depressed. In December 1943,⁴⁶ the Surgeon of the Fifth Army issued a directive in which it was stated that in all cases in which the blood supply to an extremity is impaired the extremity should be depressed. The *Manual of Therapy* issued in the European Theater of Operations, 5 May 1944, listed as a measure for the control of hemorrhage the following: "Elevation of the part. This should be done with due care of associated fractures, regardless of the local methods used." Circular No. 8, dated 10 March 1945, issued from the office of the Surgeon, Mediterranean Theater of Operations, stated: "The position of an extremity is important, as elevation may accentuate ischemia. A dependent position is preferable even if a moderate degree of edema appears to be the result." This warning was also repeated elsewhere.⁴⁷

These altered instructions reflected the conflict of opinion on this subject which existed in civilian practice and can be attributed to failure to distinguish between peripheral edema per se and peripheral edema associated with acute arterial injuries. In these injuries, particularly in acute occlusions of the main blood supply to a limb, the blood flow to the part was impeded and had to be maintained through the collateral circulation. Elevation of the extremity above the level of the heart accentuated the ischemia by forcing the blood flow to overcome the amount of gravity pull created by this position. Against this argument was the fact that edema in the tissues, which under ordinary circumstances would be treated by elevation of the limb above the level of the heart, was undesirable in arterial injuries for a number of reasons: It disrupted tissue and predisposed to fibrosis. It compressed and occluded small vessels. It increased the barrier to the transport of metabolic products to and from the blood. The edema which occurred in battle injuries was therefore as undesirable as edema always is, but it was the result, in part at least, of ischemia which would be increased and not reduced by elevation of the limb above heart level. When confronted with this choice it therefore seemed more reasonable to maintain the extremity in a slightly dependent position, or possibly at heart level, and to regard the edema as the lesser of two evils. Alternate raising and lowering of the limb for brief periods was suggested as a solution of the problem, but careful judgment was essential to be certain that elevation did not do more harm than good by increasing the period of ischemia.

⁴⁵ See footnote 22 (1), p. 70.

⁴⁶ Essential Technical Medical Data from Overseas Forces, Hq NATOUSA, 23 Dec 43. HD: 350.05.

⁴⁷ See footnote 28, p. 81.

Some authorities were not in agreement with this point of view. Cohen,⁴⁸ for instance, advocated elevation of the limb on the ground that this position does not empty the arterial tree and cause capillary anoxia. He stated that elevation by diminishing venous pressure and increasing lymph flow prevents edema which will compress the capillaries. The experience of American surgeons, however, confirmed the desirability of placing the extremity in a slightly dependent position.

Physiologic rest of the injured limb was essential both to reduce to a minimum the nutritional needs of the tissues and to limit infection and absorption of toxic by-products. These objectives were best accomplished by placing the extremity in a well-padded posterior plaster shell made by splitting a long tubular plaster cast. The limb could then be lowered onto a support off the side of the bed or kept in a dependent position by some other means.

Oxygen Therapy. Since lack of available oxygen is one of the factors responsible for death of tissue after vascular occlusion, oxygen inhalation seemed a reasonable method of supplying the lack in acute vascular injuries. An increase in the oxygen saturation of the blood could be easily effected by this means when oxygenation was impaired by thoracic wounds or similar causes. Under normal respiratory conditions, however, the increase in the partial pressure of oxygen in the inspired air had little effect upon the oxygen content of the blood. The slight increase (15 percent) was made possible by an increase in the amount of oxygen dissolved in the plasma. Whether or not this increase resulted in a sufficient increase in the oxygen gradient between capillary blood and the rest of the tissues to affect the outcome in arterial injuries seemed doubtful, especially in view of the difficulties inherent in the use of the method under combat conditions. It was the consensus that better results would be achieved by devoting the same amount of effort to correction of oligemia and anemia with the objective of improving the oxygen-carrying capacity of the circulating blood.

Anticoagulant Therapy. Anticoagulant therapy, in spite of its value in selected vascular surgery cases in civilian practice, had an extremely limited application in the military setup in overseas theaters. Its use, as already pointed out, was impractical immediately after wounding because the criteria of its employment, close clinical observation and repeated laboratory studies, could not usually be met. Mere arrival of the patient at a hospital did not meet these criteria. For one thing, the vascular injury had to be the only injury; the use of an anticoagulant agent if the patient had other injuries was contraindicated for obvious reasons. Moreover, while it may be theoretically possible in a civilian hospital or a Zone of Interior installation to employ heparin or some similar agent before operation and to control the clotting time during the procedure, this could not be regarded as either practical or safe in an overseas forward area.

⁴⁸ Cohen, S. M.: Traumatic arterial spasm. *Lancet* 1: 1-6, 1 Jan 44.

Another, and perhaps the chief, reason for not employing anticoagulant therapy in most combat-incurred vascular injuries was that by the time the patient could be transported to a hospital equipped to administer it, too much time had elapsed for the measure to be of any benefit. Thrombosis usually had occurred, and the distal portion of the extremity had been deprived of blood for too long a period for the pathologic changes which follow in the absence of circulation to be reversible.

In spite of these obstacles to its routine employment, in a few cases of battle injuries in which anticoagulant therapy was indicated and in which conditions permitted careful, continuous observation and adequate laboratory checks, the method had a definite field of usefulness and was employed.

Data are not available as to how often anticoagulant therapy was used in vascular wounds by American surgeons in World War II, although it is known that it was employed only rarely. In 1 sample of 12 cases in which it was instituted (it was usually administered in Pitkin's menstruum)⁴⁹ as early as was considered feasible under the military conditions and in which careful studies were made, no significant advantages were observed from its use.⁵⁰ Langley⁵¹ suggested a continuous saline drip as a more effective mode of administration than intermittent intravenous injection. He also regarded the generally accepted dosage as insufficient.

The Use of Refrigeration. The concept of reducing the metabolism of an injured part by cooling to make metabolic activity commensurate with whatever circulation remains in the limb is theoretically sound and had attracted some attention before World War II.⁵² On the other hand, the wisdom of actual refrigeration of a limb in which the circulation is for any reason impaired is still open to question unless the objective is to control infection and diminish lymphatic absorption prior to amputation, or to permit amputation without anesthesia in an aged and debilitated subject.⁵³

Bruneau and Heinbecker⁵⁴ showed that under experimental conditions the clinical application of cold (6° C.) to infected tissues was of no therapeutic value per se, and when the application was continued for periods of 24 to 96 hours, there were definite changes in tissue hydration, pronounced vasodilatation, and a decrease in the growth-resisting action of the tissues toward bacterial

⁴⁹ Loewe, L., Rosenblatt, P., and Lederer, M.: A new method of administering heparin. *Proc. Soc. Exper. Biol. & Med.* 50: 53-55, May 1942.

⁵⁰ Simeone, F.: Wounds of the arteries of the extremities. Report to the Surgeon, Mediterranean Theater of Operations, Aug 1945. HD: 350.05.

⁵¹ Langley, G. F.: Repair of ruptured popliteal artery, with note on heparin therapy after arterial suture. *Brit. J. Surg.* 31: 161-165, Oct 1943.

⁵² (1) Blalock, A.: Effects of lowering temperature of injured extremity to which a tourniquet has been applied. *Arch. Surg.* 46: 167-170, Feb 1943.

(2) Freeman, N. E.: Influence of temperature on development of gangrene in peripheral vascular disease. *Arch. Surg.* 40: 326-333, Feb 1940.

⁵³ (1) De Takats, G., and Miller, D. S.: Use of direct heat and indirect heat to increase blood flow to the extremities. *War Med.* 2: 429-436, May 1942.

(2) Richards, V.: Refrigeration anesthesia in surgery. *Ann. Surg.* 119: 178-200, Feb 1944.

⁵⁴ Bruneau, J., and Heinbecker, P.: Effects of cooling on experimentally infected tissues. *Ann. Surg.* 120: 716-726, Nov 1944.

organisms. These changes became more severe as the period of refrigeration was prolonged. They concluded their article by stating: "While the exact clinical limitations of the procedure remain to be determined, this would contraindicate, except for brief periods, the cooling to levels around 6° C. of infected limbs which one aims to save by conservative measures." Large and Heinbecker⁵⁵ noted in 1944, as Brooks and Duncan⁵⁶ had previously noted, that healing progressed less satisfactorily after refrigeration, and they also called attention to the possibility of nerve injury following prolonged cooling of an extremity.

Throughout the war some observers continued to advocate the refrigeration of the wounded extremity. They argued that application of ice packs would gradually produce anesthesia in the injured part and allow painless transportation of the wounded soldier which is a considerable factor in the prevention of secondary collapse from continued pain, bacterial growth would be inhibited by refrigeration therapy because of decreased oxidation, and enzymes and toxins would be temporarily inactivated. A dirty wound would, therefore, be maintained in a stationary condition until debridement could be carried out. It was also pointed out that when refrigeration was continued following definitive treatment because of irreparable vascular damage it had to be continued until the collateral circulation was reestablished, vasospasm was overcome, thrombosed vessels recanalized, or until failure was evident. In any event, it had to be withdrawn slowly to prevent the rapid spread of gangrene or infection.

Regardless of the logic or the fallacy of this line of reasoning, refrigeration, as already pointed out, was only occasionally a practical procedure in hospitals of a combat zone, while the transportation of a wounded soldier through channels of evacuation with repeated replacement of ice packs on his wounded limb was a concept which no experienced military surgeon could possibly contemplate.

Refrigeration was employed in 3 cases in the Mediterranean theater in which circumstances were favorable for a trial of this method. The femoral artery was the site of the wound in 1 case and the popliteal in 2 cases. Amputation was required in all 3 instances. These poor results are in accord with those reported by Auster,⁵⁷ and by Ottaway and Foote,⁵⁸ who gave the method a trial in naval casualties in the South Pacific, and by Snyder,⁵⁹ who used it in the Mediterranean and European theaters. While the amputations necessary in these cannot be attributed to the method (it was employed with great

⁵⁵ Large, A., and Heinbecker, P.: Nerve degeneration following prolonged cooling of an extremity. *Ann. Surg.* 120: 742-749, Nov 1944.

⁵⁶ Brooks, B., and Duncan, G.: The influence of temperature on wounds. *Ann. Surg.* 114: 1069-1075, Dec 1941.

⁵⁷ Auster, L. S.: Combat injuries in the South Pacific. *U. S. Nav. M. Bull.* 42: 1009-1018, May 1944.

⁵⁸ Ottaway, J. P., and Foote, J. J.: Refrigeration of wounded extremities. *U. S. Nav. M. Bull.* 43: 1041-1043, Nov 1944.

⁵⁹ Snyder, J. M.: Vascular wounds; report of a series of 108 cases encountered in a forward evacuation hospital. *Surgery* 21: 77-85, Jan 1947.

caution and careful observation) no evidence exists that this method has saved limbs after wounds of the major arteries. Indeed its prolonged use, as has already been indicated, can lead to damage of the tissues that it is expected to preserve.

While the direct application of cold to the injured limb was not advocated, it was recommended that the temperature of an extremity to which a tourniquet had been applied should be lowered as much as was feasible short of actual freezing.

The Use of Heat. While the application of cold to an injured limb was considered unwise and ineffective, the direct application of heat was also considered to be contraindicated. The direct use of heat had several undesirable effects: It speeded up local tissue metabolism in a part in which the circulation was already inadequate for the demands upon it. Since the heat could not be carried away by the vessels which were damaged, its effect was cumulative, and the possibility of damage to the tissues was increased. Finally, heat increased capillary stasis and thereby increased local edema and delayed wound healing. For these reasons it was the practice to leave the injured limb uncovered and exposed to room temperature. If the patient complained of cold the limb could be lightly covered with a wool or cotton cover, but it was never placed under bed covering.

Conservation of the body heat was, on the other hand, an important part of treatment. This was accomplished by the use of blankets, or an electric cradle, or hot water bottles. Warming was frequently necessary because of exposure or as part of the treatment of shock, but, in addition, it had a beneficial effect on the wounded limb in that it relaxed the peripheral vessels, favored the development of a collateral circulation, and encouraged the relaxation of vasospasm.

SURGICAL MEASURES

Debridement

There was every reason for not omitting debridement in most battle-incurred wounds. No matter how innocent the wound might look from the outside, there might be considerable shattering and destruction of tissue in its depths which could be visualized only through adequate incisions in the skin and fascial planes. When a wound was thus explored it was common to find beneath even a small wound of entrance foreign bodies, bits of clothing, devitalized muscles, hematomas, and major vascular damage. The surgical excision of devitalized tissue was part of the resuscitative program; it minimized the incidence of gas bacillus and other infections, and it had a favorable effect on vasospasm of any degree which might be present in an injured artery which had not lost its integrity. This was first pointed out in Circular Letter No. 178, Office of The Surgeon General, dated 23 October 1943, and was reiterated at intervals thereafter until the end of the war.

Arterial Ligation

The affected artery had to be ligated in the majority of the vascular injuries which came under the military surgeon's observation in World War II. It was never the procedure of choice, but one of stern necessity required by the location, type, size, and character of the wound.

Not a great deal need be said about the optimal site of ligation. In World War II, when wound infection was usually a controllable complication and secondary hemorrhage was not the factor of risk which it was in World War I, there was seldom any justification for proximal ligation. While it is desirable theoretically to ligate the vessel at such a level as to avoid the creation of a blind pouch, the deliberate effort to do so frequently involves extensive dissection and may still further jeopardize the circulation of the injured limb.

Ligation in continuity was not favored in World War II.⁶⁰ Instead, non-absorbable sutures were placed well above and well below the site of injury or thrombosis and the damaged intervening segment was excised. This technique eliminated the dangers of secondary hemorrhage, thrombosis, and vasoconstrictor influences. Division permitted the ends of the vessel to retract and suppressed generalized vasospasm. Embolism at the site of ligature was also less likely to take place in a divided vessel.

On the other hand, when it was possible to tie the artery just below a large branch rather than leave a blind end to which the blood flowed with each pulse beat, it was best to do so. Rogers⁶¹ emphasized that there was less interference with the hand and fingers when the brachial artery was tied just distal to the origin of the superior profunda. Rogers also advised the rapid transfusion of 800 to 1,200 cc. of blood during ligation to increase the blood pressure and force the capillaries open.

All the experience of World War II suggested that the best results were achieved in vascular injuries in which ligation was required if the operation could be delayed for at least several days. In selected cases the possible development of an aneurysm was therefore accepted as a calculated risk if delay could thus be achieved.

Ligation of the Concomitant Vein. The chief difference in the technique of arterial ligation as it was performed in the two World Wars concerns the ligation of the concomitant vein along with the injured artery. The amount of space devoted in the literature to the discussion of this procedure and the emphasis put upon it in World War I and in the early years of World War II are curiously out of proportion to its value.⁶²

⁶⁰ See footnotes 22 (1), and (3), p. 70; and 29, p. 81.

⁶¹ Rogers, L.: Physiological considerations in vascular surgery; ligation of main arteries to the limbs. M. J. Australia 1: 517-518, 19 May 45.

⁶² See footnotes 22 (1), p. 70; and 23, p. 71.

Therapeutic venous ligation has been known since the time of Hippocrates. as Brooks⁶³ points out in his review of the subject, and has always been widely practiced for venous disease. Makins seems to have been the first to suggest that it be part of the treatment of acute traumatic arterial lesions. His experiences in the South African War convinced him that the incidence of gangrene following surgery for traumatic arteriovenous fistula was less when both artery and vein were ligated than when only arterial ligation was done, but he did not record the observation until his Bradshaw Lecture in 1913.⁶⁴ Moreover, in his extensive article on vascular injuries of warfare published in 1916⁶⁵ he dismissed the procedure rather casually, with the remark: "With regard to the question of the danger of simultaneous ligature of the artery and vein, it may be added that this was done in one of the successful cases."

In the Hunterian Oration, however, which was delivered in 1917⁶⁶ he advocated the deliberate ligature of the uninjured concomitant vein in cases of arterial occlusion, and at this time, as well as in his monograph⁶⁷ published after the war, he set forth the evidence on which he based his advocacy. This evidence may be briefly summarized as follows:

1. The demonstration in varicose veins of the ease with which a compensatory balance is attained when blood is diverted from the larger channels.
2. The absence of permanent vascular difficulties when the jugular and other large veins are ligated to prevent the diffusion of septic emboli.
3. The possibility of survival after occlusion of the vena cava.
4. Personal experience with arteriovenous fistula to the effect that quadruple ligation and excision are less dangerous than simple arterial ligation.
5. Von Oppel's good results⁶⁸ with this technique in 6 cases of senile gangrene resulting from occlusion of the popliteal artery. (Von Oppel used this method because of his observation of the occasional good results which followed arteriovenous anastomosis in this condition and which he attributed to control of the venous circulation and consequent rise in the blood pressure of the limb.)

⁶³ Brooks, B.: Surgical applications of therapeutic venous obstruction. *Arch. Surg.* 19: 1-23, Jul 1929.

⁶⁴ Makins, G. H.: The Bradshaw Lecture on gunshot injuries of the arteries. *Lancet* 2: 1743-1752, 20 Dec 13. *Also* *Brit. M. J.* 2: 1569-1577, 20 Dec 13.

⁶⁵ Makins, G. H.: On the vascular lesions produced by gunshot injuries and their results. *Brit. J. Surg.* 3: 353-421, Jan 1916.

⁶⁶ Makins, G. H.: The Hunterian Oration on the influence exerted by the military experience of John Hunter on himself and the military surgeon of today. *Lancet* 1: 249-254, 17 Feb 17.

⁶⁷ See footnote 12, p. 64.

⁶⁸ (1) Von Oppel, W. A.: Zur operativen Behandlung der arteriovenösen Aneurysmen. *Arch. f. clin. Chir.* 86: 31-52, 1908.

(2) Von Oppel, W. A.: Reduzierte Blutkreislauf. *International Congress of Medicine*, 1913. London, Oxford University Press, 1913, pt 1, p. 189.

(3) Von Oppel, W. A.: Wieting's Operation und der reduzierte Blutkreislauf (*Wratschebnaja Gaz.* 1913, No. 9). *Zentralbl. f. Chir.* 40: 1241, 2 Aug 13.

(4) Von Oppel, W. A.: Die Theorie des umgekehrten und perversen Blutlaufs in den Extremitäten (*Russki Wratsch* 1913, No. 15). *Zentralbl. f. Chir.* 40: 1242, 2 Aug 13.

6. Drummond's experimental demonstration⁶⁹ that gangrene follows ligation of the mesenteric artery but does not follow ligation of the mesenteric artery and vein.

7. Van Kend's experimental studies⁷⁰ which showed a local rise of blood pressure in the affected limb when the concomitant vein was ligated subsequent to occlusion of the artery.

This was the evidence on which Makins based his observations, and he advanced, in addition, two other reasons why ligation of the concomitant vein was of distinct advantage:

1. The capacious main vein affords too ready a channel of exit for the diminished arterial supply, as well as an undesirable reservoir of stagnation.

2. As the result of combined arteriovenous ligation, the smaller amount of blood supplied by the collateral arterial circulation is maintained for a longer time within the limb, with the result that there is an improvement in the conditions necessary to preserve its vitality.

Aside from Makins' statistics, not a great deal of evidence for or against ligation of the concomitant vein can be found in the literature of World War I. In 1916 (that is, before Makins' observations were published), Sehrt⁷¹ reported that when the artery alone was ligated the incidence of gangrene in the upper extremity was 7.8 percent, but when the concomitant vein was also ligated there was no incidence of gangrene. The corresponding figures for the lower extremity were 20.4 percent and 9.0 percent. On the basis of this experience, the author concluded that ligation of the concomitant vein was of distinct value and that the "impounding of venous blood in the extremity" was beneficial. It is not clear on how many cases his observations were based. Propping⁷² in 1917 attempted to provide experimental evidence to support the opinion that concomitant vein ligation is beneficial, and while the experiment was rather naive he concluded from it that ligation of the concomitant vein was beneficial since gangrene of the limb after ligation of an artery is the result of an imbalance between the amount of blood entering the extremity and the amount leaving it through the veins.

The whole matter was fully discussed at the Inter-Allied Conference of Surgeons held in Paris in May of 1917, and on the basis of Makins' statistics (Chart 13) it was agreed that the concomitant vein should be ligated whenever a major artery was ligated, even if the vein itself was not injured.⁷³

⁶⁹ Drummond, Hamilton: Quoted by Makins (footnote 12, p. 64).

⁷⁰ Van Kend: Sur les blessures des vaisseaux, 6^e Séance, 17 May 17. Arch. de Méd. et de Pharm. mil. 68: 348-349, Jul-Aug-Sep, 1917.

⁷¹ Sehrt, E.: Über die künstliche Blutleere von Gliedmassen und unterer Körperhälfte, sowie über die Ursache der Gangrän des Gliedes nach Unterbindung der Arterien allein. Med. Klin. 12: 1338-1341, 17 Dec 16.

⁷² Propping, Karl: Über die Ursache der Gangrän nach Unterbindung grosser Arterien. München. med. Wchnschr. 64: 598-599, 1 May 17.

⁷³ (1) Depage, A.: Blessures des Vaisseaux. Comptes-Rendus de la Conférence Chirurgicale Interalliée pour l'étude des plaies de guerre, 5^e Séance, 16 May 17. Arch. de Méd. et de Pharm. mil. 68: 324-328, Jul-Aug-Sep 1917.

(2) Jacob: Blessures des Vaisseaux. Comptes-Rendus de la Conférence Chirurgicale Interalliée pour l'étude des plaies de guerre, 5^e Séance, 16 May 17. Arch. de Méd. et de Pharm. mil. 68: 328-340, Jul-Aug-Sep 1917.

(3) Makins, G. H.: Blessures des Vaisseaux. Comptes-Rendus de la Conférence Chirurgicale Interalliée pour l'étude des plaies de guerre, 6^e Séance, 17 May 17. Arch. de Méd. et de Pharm. mil. 68: 341-348, Jul-Aug-Sep 1917.

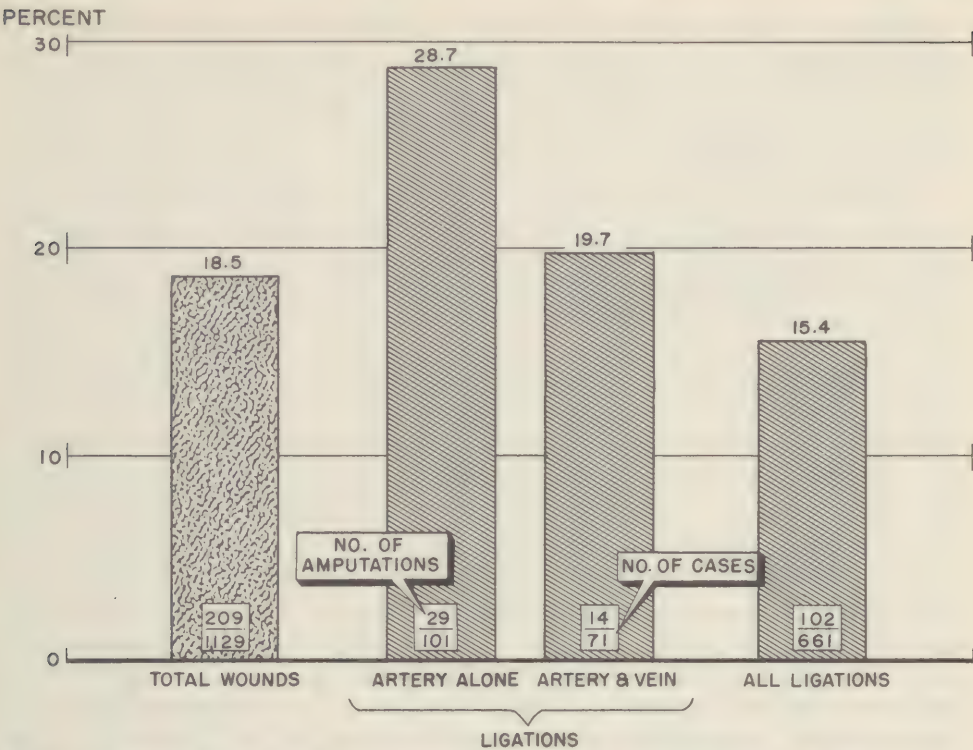


Chart 13. Results of ligation of comparable arteries with and without ligation of concomitant veins in British casualties in World War I. These data include only those cases where for the same artery, there were examples with and without concomitant vein ligation.

This conclusion was a complete reversal of the attitude which had prevailed before World War I when the current opinion seemed to be that the prognosis for survival of a limb after interruption of a major artery was worse when the concomitant vein was injured and had to be ligated simultaneously. Under these circumstances, Jacobson⁷⁴ wrote, "Leave should be gotten at once for amputation," while Matas⁷⁵ declared that "the danger of peripheral gangrene is always made doubly worse by the simultaneous injury of the accompanying or satellite vein."

Even after World War I, all surgeons did not accept the new point of view unreservedly. In 1921 Punin⁷⁶ on the basis of 64 personal and 1,057 collected cases of arterial injury concluded that the incidence of gangrene was no less after the combined procedure than it was when ligation of the vein was omitted. In the same year Maurer⁷⁷ stated guardedly that concomitant

⁷⁴ Jacobson, W. H. A.: The Operations of Surgery, 6th edition by R. P. Rowlands & Philip Turner. London, J. & A. Churchill, 1915, vol 1, p. 843, 894.

⁷⁵ Matas, R.: Surgery of the vascular system. In Keen, William W.: Surgery—Its Principles and Practice, by Various Authors. Philadelphia and London, W. B. Saunders Company, 1921, vol 5, pp. 17-350.

⁷⁶ Punin: Cited by Franz (footnote 17, p. 64).

⁷⁷ See footnote 14, p. 64.

vein ligation is not harmful and might be advantageous (in 1939 ⁷⁸ he was even less enthusiastic). The weight of Makins' prestige, however, was so great that his point of view was usually accepted without question, and the practice of ligation of the concomitant vein became the rule when certain arteries, at least, had to be ligated.

Brooks,⁷⁹ in 1929, in his extensive review of the subject decided on the basis of clinical and experimental evidence ⁸⁰ that the concomitant vein should be ligated when the popliteal or axillary arteries were injured but when the common femoral artery was injured he believed it wiser to close the wound without ligating the vein and to watch the extremity carefully for signs of impending gangrene. The vein should be ligated only if such signs became evident. When the femoral and brachial arteries were damaged he believed that it made little difference whether or not ligation of the concomitant vein was done. In 1933 Wilson ⁸¹ published an article which controverted the opinion that ligation of the concomitant vein diminished the incidence of gangrene following ligation of the main artery. If venous ligation was done at a higher level than the arterial ligation, he concluded, both the incidence and extent of tissue death would be increased. This study received indirect support from the observations which Montgomery ⁸² had published in 1929 which showed that the per-minute flow of blood to the extremity was still further reduced if the concomitant vein was ligated in an extremity in which the artery had previously been ligated. Then, in 1934, Brooks ⁸³ and his co-workers published an article on their results of an experimental study of 220 rabbits which showed that massive gangrene of the extremity was 14.5 times less frequent after arterial and venous ligation than after arterial ligation alone.

While the experimental evidence for and against ligation of the concomitant vein is thus rather inconsistent, there seems no doubt, as Wilson ⁸⁴ pointed out, that Makins' reasoning in favor of the procedure was not based upon sound physiologic concepts. Moreover, Makins' frequently quoted statistics,⁸⁵ when they are carefully examined, do not seem to warrant the sweeping conclusions

⁷⁸ Maurer, A.: Note sur les plaies vasculaires récentes et leur traitement d'après 444 observations. *Mém. Acad. de chir.* 65: 1156-1164, 25 Oct-8 Nov 39.

⁷⁹ See footnote 63, p. 103.

⁸⁰ (1) Brooks, B., and Martin, K. A.: Simultaneous ligation of vein and artery; an experimental study. *J. A. M. A.* 80: 1678-1681, 9 Jun 23.

(2) Holman, E., and Edwards, M. E.: A new principle in the surgery of the large vessels; ligation of vein proximal to site of ligation of artery; an experimental study. *J. A. M. A.* 88: 909-911, 19 Mar 27.

(3) Pearse, H. E., Jr.: A new explanation of the improved results following ligation of both artery and vein. *Ann. Surg.* 86: 850-854, Dec 1927.

(4) Theis, F. V.: Ligation of artery and concomitant vein in operations on large blood vessels. *Arch. Surg.* 17: 244-258, Aug 1928.

⁸¹ Wilson, W. C.: Occlusion of the main artery and main vein of a limb. *Brit. J. Surg.* 20: 393-411, Jan 1933.

⁸² Montgomery, M. L.: Effect of therapeutic venous ligation on blood flow in cases of arterial occlusion. *Proc. Soc. Exper. Biol. & Med.* 27: 178-179, Nov 1929.

⁸³ Brooks, B.; Johnson, G. S., and Kirtley, J. A., Jr.: Simultaneous vein ligation; an experimental study of the effect of ligation of the concomitant vein on the incidence of gangrene following arterial obstruction. *Surg., Gynec. & Obst.* 59: 496-500, Sep 1934.

⁸⁴ See footnote 81, above.

⁸⁵ See footnotes 3, p. 60; and 12, p. 64.

which have been drawn from them. For one thing, it is not possible to separate the cases of acute arterial injury from the cases of arteriovenous fistula, nor is it possible to determine the proportions of aneurysms in the two groups of cases. For another, the difference between the incidence of amputations in the series in which only arterial ligation was done and the series in which the concomitant vein was ligated also is not statistically significant. Finally, the incidence of amputations in the whole group of wounds of arteries in Makins' collected World War I series (Chart 13) is actually less than the incidence of amputations in the comparable series in which the concomitant vein was ligated, though the former series, on the basis of his theories, should provide the larger number (or at least an equal number) of poor results.

Makins' concepts were undoubtedly responsible for the persistence into World War II of the idea that concomitant venous ligation was useful in arterial injuries. Hoche,⁸⁶ in 1940, warned against ligation of certain arteries, such as the popliteal and the femoral artery above the branching off of the deep femoral, without simultaneous ligation of the concomitant vein on the ground that disturbances resulting from arterial injury and ligation seemed to result not so much from failure of the collateral circulation as from a disparity between the collateral arterial inflow and the venous discharge. Decker,⁸⁷ in 1941, recommended ligation of the jugular and popliteal veins when the corresponding arteries were ligated. He suggested, however, when other vessels were concerned, that temporary pressure be applied to the vein after the artery had been ligated and that the subsequent procedure depend upon developments: If after a few minutes the peripheral circulation was found to be favorably affected by this maneuver, ligation of the appropriate vein should be done, while if no effects were observed it should not be done.

Although ligation of the concomitant vein was recommended in circular letters and other material issued to American medical officers in World War II as late as D-day in Europe,⁸⁸ the American experience with the method was not extensive (Chart 14). The majority of surgeons did not use it routinely, if at all, and the experience of no single surgeon was large enough to permit valid conclusions. The collected figures seem to indicate that ligation of the concomitant vein does not in any way increase the chance of survival of the limb. The difference between the incidence of amputations in the cases in which the vein was ligated and in the cases in which it was not ligated is not statistically significant. As in the British figures for World War I, the incidence of amputation in the total group of arterial wounds was considerably less than it was in the comparable group in which concomitant vein ligation was done. The difference, in fact, is statistically significant, although if the procedure were of

⁸⁶ Hoche, O.: Die wehrchirurgische Behandlung der Verwundeten. Die Blutung und ihre Behandlung. *Med. Klin.* 36: 919-922, 16 Aug 40.

⁸⁷ Decker, P.: L'hémostase d'urgence en chirurgie de guerre. *Helvet. med. acta* 8: 3-21, Apr 1941.

⁸⁸ See footnote 23, p. 71.

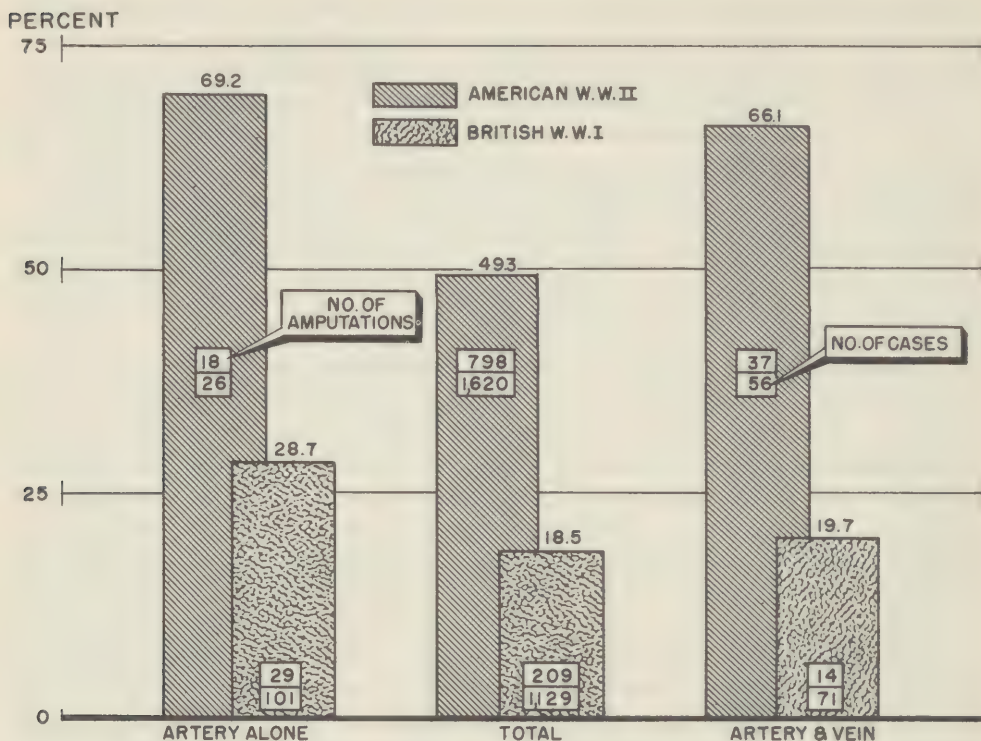


Chart 14. Results of ligation of comparable arteries with and without ligation of concomitant veins among British casualties in World War I and American casualties in World War II. These data include only those cases where, for the same artery, there were examples with and without concomitant vein ligation.

definite value one would expect the results of venous ligation to be at least as good, if not better.

The conclusion therefore seems warranted that ligation of the concomitant vein in combat-incurred arterial wounds furnishes no protection whatsoever against the development of gangrene after acute arterial occlusion treated by ligation.

Primary Amputation

Circular letters and directives issued in the Mediterranean and other overseas theaters⁸⁹ and information disseminated from the Surgeon General's Office⁹⁰ limited primary amputation to cases in which the extremity was irreparably damaged or devoid of circulation. Primary amputation was also permitted in an occasional case for the control of hemorrhage or as the first

⁸⁹ (1) See footnote 23, p. 71.

(2) Cir Ltr 101, Off of Chief Surg ETO, 30 Jul 44, sub: Care of battle casualties.

(3) Cir Ltr 23, Off of Chief Surg ETO, 17 Mar 45, sub: Care of battle casualties.

⁹⁰ See footnotes 28 and 29, p. 81.

step of treating a traumatic amputation which is not complete. The site of amputation was the lowest possible level of viable tissue regardless of the utility of the stump. The warning was frequently issued that the line of demarcation in an infected extremity which was the site of a vascular occlusion did not mark the level at which an amputation stump could be maintained, since circulation sufficient only to maintain tissue viability could not cope with infection.

When amputation was necessary the entirely proper desire to delay it in order to permit the establishment of an adequate collateral circulation had to be weighed against the possible systemic reaction, the local evidence of infection, and the practicability of keeping the patient under observation. In an active theater of war the latter consideration was of great importance. At echelons in which evacuation might be necessary on short notice, it was sometimes better to amputate a limb in which gangrene had developed as promptly as possible rather than risk complications during the time of evacuation when the patient was not being closely observed.

Suture Repair

World War I. On theoretical grounds, repair of a damaged artery by suture offers the chief hope of survival of the limb but practically, as has been pointed out, reparative measures are seldom applicable in military surgery. The value of suture was recognized during World War I but, as in World War II, the number of cases to which it could be applied was very small. It is the only method, Makins⁹¹ stated, which provides ideal results, but he added that it is applicable only in the primary state of vascular injuries and only if infection can be avoided. He regarded lateral wounds of the carotid, femoral, and popliteal arteries as the most suitable sites for its performance and placed the axillary and brachial arteries in the next category. Sencert⁹² also wrote that ligature is the method *par excellence* for the arrest of hemorrhage from recent vascular wounds, but he added, like Makins, that the indications for its performance are few.

Bernheim's experiences⁹³ in World War I were illuminating. He had enthusiastically practiced the Carrel⁹⁴ method of suture in his civilian practice and went to France with elaborate personal equipment in order to use the method in military surgery. In nearly 2 years overseas, however, he never saw any other surgeon suture an artery and he himself discontinued it in the few cases in which he attempted it because of loss of supporting tissue as the result of necessary debridement, and because of the unjustifiable amount of time which the operation required. Even in cases in which infection was

⁹¹ See footnote 3, p. 60.

⁹² See footnote 38, p. 84.

⁹³ (1) Bernheim, B. M.: Blood-vessel surgery in the war. *Surg., Gynec. & Obst.* 30: 564-567, Jun 1920.

(2) Bernheim, B. M.: Symposium on emergency treatment; management of vascular injuries. *S. Clin. North America* 22: 1417-1426, Oct 1942.

⁹⁴ Carrel, A.: Surgery of blood vessels. *Bull. Johns Hopkins Hosp.* 18: 18-28, Jan 1907.

absent he thought that military circumstances were unpropitious for vascular suture, while "only a foolhardy man," he remarked, "would have assayed suture of arterial or venous trunks in the presence of infections such as were the rule in almost all the injured."

Goodman's experience⁹⁵ with vascular suture made him, like Bernheim, enthusiastic about the method, and after a months stay on the British Front in 1917, he felt "enabled to refute the deductions made by the other surgeons present," these being that the risk of gangrene after arterial ligation was sufficient to justify immediate amputation in injuries of the femoral and popliteal arteries, and even the posterior tibial artery. Goodman's personal experience with vascular suture, however, was limited to 5 cases, in 1 of which amputation was later required because of gangrene. In addition to his own cases, he collected a number of others, but the large proportion of aneurysms included limits their values for comparative purposes. Many cases in the collection were of German origin and there is no doubt that German surgeons used suture more frequently than either British or American surgeons in World War I, though many series, such as that reported by von Haberer,⁹⁶ consisted entirely or chiefly of aneurysms. Makins⁹⁷ was able to collect only 39 cases of arterial suture from the British experience. Three patients died, all from infection, and ideal to good results were obtained in about one-half of the remaining cases, the results being "in no way inferior to those of ligation," which seems somewhat faint praise. Gnilyorbov,⁹⁸ writing in 1944, stated that during World War I he had performed vascular suture in a number of cases (he did not cite exact figures) and that he saw no instance of gangrene after its use, in contrast to ligation, after which half of his patients developed gangrene.

Decker⁹⁹ furnishes an interesting and probably correct interpretation of why arterial suture was practiced in the early part of World War I by the surgeons of the Central Powers but infrequently during the second half. This was not the result of the tactical situation, although mobile warfare gave way to stationary trench warfare during the course of the war, but of a change in the character of the missiles used. At the beginning of World War I projectile wounds were usually inflicted from a distance, the explosive effect in the tissues was minimal and vascular injuries were therefore frequently suitable for repair-

⁹⁵ (1) Goodman, C.: A histological study of the circular suture of the blood vessels. *Ann. Surg.* 65: 693-703, Jun 1917.

(2) Goodman, C.: Suture of blood-vessel injuries from projectiles of war. *Surg., Gynec. & Obst.* 27: 528-529, Nov 1918.

(3) Goodman, C.: Surgery of the Heart; Blood Vessels, Thrombosis and Embolism and Blood Transfusion. *Cinq. Cong. de Soc. Internat. de Chir.*, Paris, 19-23 Jul 20, p. 244-263. Brussels, M. Hayez, 1921.

(4) Goodman, C.: Suture repair of war injuries to the blood vessels. *J. Internat. Coll. Surgeons* 6: 127-131, Mar-Apr 1943.

⁹⁶ (1) Von Haberer, H.: Diagnose und Behandlung der Gefäßverletzungen. *München. med. Wehnschr.* 65: 363-367; *idem, ibid.*: 405-409, Apr 1918.

(2) Von Haberer, H.: Surgery of the blood vessels in wartime. *München. med. Wehnschr.* 87: 849-851, 9 Aug 40. *Abstr., Internat. S. Digest* 31: 21-24, Jan 1941.

⁹⁷ See footnotes 3, p. 60; and 12, p. 64.

⁹⁸ Gnilyorbov, T. E.: One Hundred and Thirty Operations on the Blood Vessels. *Khirurgiya* No. 8, 40-35 (*sic*), 1942. Moscow. *Abstr., Bull. War Med.* 4: 452-453, Apr 1944.

⁹⁹ See footnote 87, p. 107.

ative surgery. Later in the war when bombs, mines, and similar weapons prevailed and were discharged at close range, this favorable circumstance ceased to exist.

World War II. In World War II the circumstances were propitious for a trial of arterial suture in that thorough debridement, supplemented by chemotherapy and antibiotic therapy, greatly reduced the risk of infection. Nevertheless, this method was not very widely employed. One reason was that it is not a technique suitable for all types of wounds. Although it can be employed in lateral injuries of some size, or in incomplete or complete transections, the most favorable type of injury is the small lateral wound. A second reason was the frequently uncontrollable length of the time between wounding and treatment, an unavoidable military circumstance.

Case 7. A soldier who was wounded by enemy shell fragments in Italy, 5 January, incurred a wound of the right popliteal fossa with laceration of the popliteal area. There was no fracture. The laceration was sutured on 7 January at an evacuation hospital and right lumbar sympathetic block was done.

Between 11 January and 20 January four different operations were performed on the patient for local excision of gangrenous skin and muscle. On 2 February, at a general hospital, a guillotine-type of amputation was done for infection and loss of tissue caused by ischemia.

Comment. The details are lacking in this case, the history of which was secured from proceedings of a disposition board, but the most significant fact is known, that arterial suture was done more than 24 hours after wounding. This is well past the optimum time period for repair and a good result could scarcely have been expected.

Arterial suture was performed in only 81 of the 2,471 arterial wounds analyzed in this chapter (Chart 15). Included in the group are 3 end-to-end anastomoses, which were performed on the common femoral, femoral, and popliteal arteries. Most of the other wounds were small lateral lacerations, involving a third or less of the circumference of the vessel. One was a wound inflicted accidentally with a bayonet, a type ideally suited for suture because the incision is clean and there is no great loss of tissue.

The results of suture in these 81 cases are significantly better than the results of ligation and vein graft and probably better than the results of tube anastomosis (Chart 15). That fact, however, does not offer any great encouragement, for these 81 cases were a highly selective group of minimal wounds without extensive tissue destruction. It would not be possible to duplicate, or even approach, these results in the usual run of arterial wounds.

Killian's observations¹⁰⁰ on arterial suture in the German Army during World War II are not helpful in this connection because, while it was performed in 52 of 72 surgical cases, an unspecified number of these were aneurysms. Recovery occurred in 50 cases, in only 5 of which amputation was necessary. The favorable results in these instances of arterial suture and early operation for aneurysms showed, according to Killian, that suture is a method which can

¹⁰⁰ Killian, H.: Über die Indikation zur Frühoperation von Gefäßverletzungen und Aneurysmen. Arch. f. klin. Chir. 204: 355-410, 26 Mar 43.

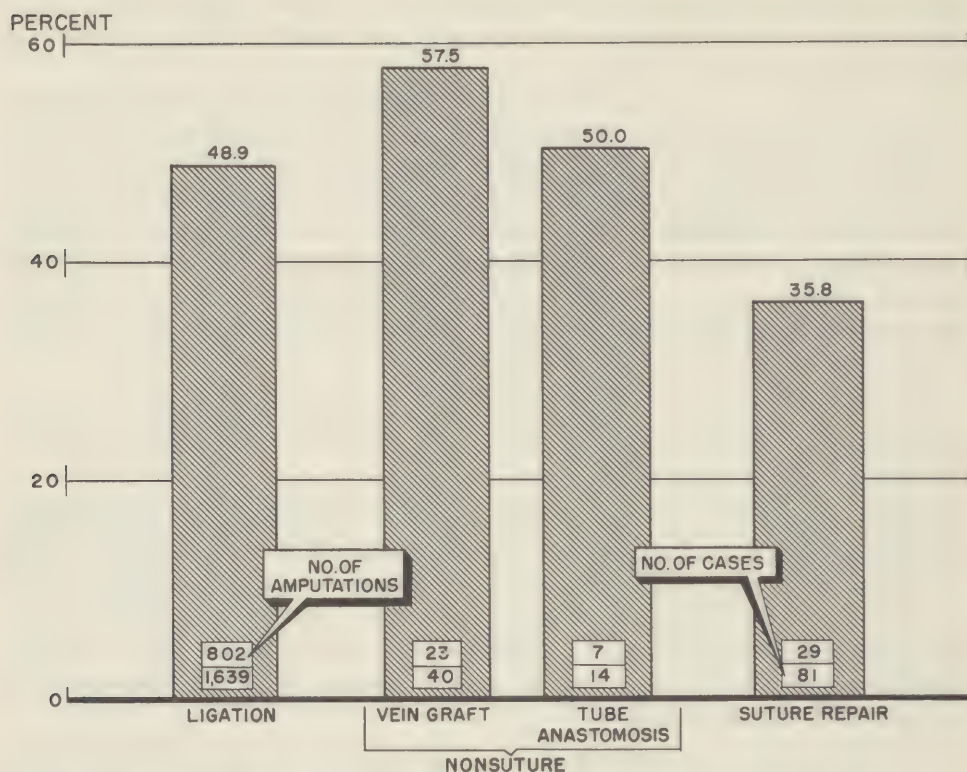


Chart 15. Results of various therapeutic measures on incidence of amputation in arterial wounds of the extremities in American battle casualties in World War II, with special reference to the type of arterial repair. The data depicted are based on a selected group for which the necessary information was available. They do not include all arterial wounds during World War II. Detailed treatment of the remaining 697 American cases shown in Table 3 consisted of amputation as a primary procedure, or is unknown.

be practiced by the field surgeon at the battlefield. Unfortunately, he does not define his terms, and this fact, together with the apparently large proportion of aneurysms included in the series, makes his observation of little value.

Complications. Thrombosis and embolism are immediate, but infrequent, complications of arterial suture. They did not appear in this series nor did any patient present signs of either arterial stricture or aneurysm during the period he was under observation. The most important immediate complication of arterial suture is hemorrhage. The records are incomplete on this point but it is known to have occurred in 2 of 24 cases in which it was possible to determine its presence or absence. It usually occurs 6 to 8 days after operation by which time a collateral circulation has developed and ligation can be done with much less risk than when it is a primary procedure. In the following case the hemorrhage which occurred shortly after operation can be considered a complication of heparinization rather than of the arterial suture.

Case 8. A soldier wounded by enemy mortar shell fragments in Italy, 17 April 1945, incurred penetrating wounds of the face, both thighs, and the right inguinal region. The latter wound caused a laceration of the common femoral artery, 4 to 5 mm. long, at the junction of the femoral and profunda femoris arteries and near the origin of the circumflex iliac artery. There were no fractures. Sulfanilamide powder was dusted into the wounds and compression bandages were applied. When the patient reached an evacuation hospital about 4½ hours after wounding, penicillin was administered promptly (25,000 units intramuscularly at 3-hour intervals).

The operation was performed, using drop-ether anesthesia, 10 hours after wounding and lasted 3 hours. The blood pressure was normal throughout and the pulse rate varied between 100 and 120 beats per minute. Debridement and exploration of the right groin revealed a large hematoma and the laceration of the femoral artery already described. It was sutured with fine silk. During the procedure hemorrhage was controlled by means of pressure supplemented by a tape placed under the common femoral artery above Poupart's ligament and kept in place for about an hour. The patient received 1,000 cc. of whole blood before operation and another 1,000 cc. during operation. The soldier had been wounded before, but had never received a transfusion. A plaster spica was applied with pressure over the wound. At the end of the operation the dorsalis pedis and posterior tibial pulses were good.

Heparin in Pitkin's menstruum, 2 cc., 200 mg. heparin, was given 5 hours after operation and later at an unrecorded hour 1 cc. was given. The following day it was given in 2-cc. amounts at 0200 and again at 0900 hours. A transfusion of 1,000 cc. of whole blood was started 5½ hours after operation and completed after midnight. Heparin was discontinued when bleeding occurred from the wound in the evening of the day after operation.

The urine voided on the day of operation was described as clear, but was not examined. Thirty-one hours after operation, however, the patient voided bloody urine (Table 5). Urinalysis at 0900 and 1000 revealed protein to be present to which a 4+ rating was ascribed. When the patient was questioned he stated that he had never been ill in the past, but he thought that during the past year he might have had "kidney trouble" because he had suffered from lumbar pain and nocturia. Examination of the urine showed no urobilinogen or urobilin. The serum urea was 98 mg. per 100 cc. and the urea nitrogen 46 mg. per 100 cubic centimeters. The blood pressure was 120 mm. of mercury systolic and 90 diastolic.

The third day after operation (20 April) the blood pressure was 130 mm. of mercury systolic and 84 diastolic. The patient was drowsy but was easily aroused. The urine voided was clear (Table 5). Circulation in the right foot was normal.

Recovery thereafter was smooth. Transfusions of 500 cc. each were given without incident on 21 and 22 April. On 27 April the wounds were sutured. When the patient was evacuated to the Zone of Interior 29 May, his wounds were well healed and the circulation in the right leg appeared entirely normal.

Comment. It was stated in this case that at no time, before, during, or after operation was it ever impossible to feel pulsations in the dorsalis pedis and posterior tibial arteries. There seems no doubt that suture of the lacerated artery was efficacious. Of special interest are the appearance of probable myoglobin in the urine and the transient azotemia (Table 5).

Sutured Vein Grafts

The extensive loss of substance caused by the extremely destructive weapons used in World War II meant that in certain of the few vascular injuries in which arterial ligation did not seem to be immediately indicated and in which suture repair was clearly impossible, some method of bridging a sizeable gap in the wounded artery had to be used in order to reestablish continuity of the artery.

TABLE 5. SPECIAL LABORATORY STUDIES (CASE 8)

Urinalyses				
Time of determination		pH	Benzidine-positive substance	Myoglobin
Date	Hour			
			<i>Mg. per 100 cc.</i>	<i>Mg. per 100 cc.</i>
19 April.....	0900	6.0	244.....	203
19 April.....	1000	5.8	82.....	54
19 April.....	1630	6.5	9.2.....	
19 April.....	2000	5.8	Trace.....	
20 April.....	0030	7.2	Faint trace.....	
20 April.....	0130	8.4	0.....	
20 April.....	0930	8.4	0.....	
20 April.....	1030	8.4	0.....	

Blood Chemistry ¹

Date	Van den Bergh reaction	Magnesium	Bromsulphalein ² retention	Nonprotein nitrogen	Creatinine
	<i>Mg. of bilirubin per 100 cc.</i>	<i>Mg. per 100 cc.</i>	<i>Percent</i>	<i>Mg. per 100 cc.</i>	<i>Mg. per 100 cc.</i>
19 April.....	3.57	2.4	0	64	1.48
20 April.....	1.81	2.5	6.17	53	1.09
22 April.....	2.16	2.1	18.6	40	0.94

Other Studies

Date	Plasma protein	Hematocrit value	Icteric Index
	<i>Gm. per 100 cc. of plasma</i>	<i>Cc. cells per 100 cc. of blood</i>	
26 April.....	7.4	33	
28 April.....	6.9	44	
15 May.....	6.7	41	
16 May.....			7

¹ Determined by Medical Board to study the treatment of the severely wounded, MTOUSA.² Five milligrams of the dye were injected intravenously per kilogram of body weight and the retention was measured 45 minutes later.

Sutured, as opposed to nonsutured, vein grafts had been used with considerable success both experimentally¹⁰¹ and clinically¹⁰² before World War I and the method was used with surprisingly good results for traumatic aneurysms in that war,¹⁰³ though apparently it was not used for acute arterial occlusion. The operation was successful in 40 of the 47 traumatic aneurysms reported by Warthmüller,¹⁰⁴ though, as Matas¹⁰⁵ emphasized, there was small reason for its use in aneurysms in the light of the successful results achieved by his own technically simpler procedure. Suture vein grafts do not seem to have been used by American surgeons in World War II but a few successful cases (chiefly aneurysms) were reported by Rehn,¹⁰⁶ Murray,¹⁰⁷ Killian,¹⁰⁸ Schneider and Bätzner,¹⁰⁹ and Khenkin.¹¹⁰

Maintenance of the Main Arterial Channel by Prosthetic Devices

Bridging of the arterial gap by intubation to provide for temporary maintenance of the blood flow seems first to have been employed clinically in 1915 by Tuffier.¹¹¹ He had used silver tubes in performing direct blood transfusion and, on the basis of his experience with them, proposed their use for bridging arterial defects. He later reported a number of successful cases. Makins¹¹²

¹⁰¹ (1) See footnote 95 (1), p. 110.

(2) Guthrie, C. C.: End-results of arterial restitution with devitalized tissue. *J. A. M. A.* 73: 186-187, 19 Jul 19.

(3) Moure, P.: Technique des greffes vasculaires appliquées au rétablissement de la continuité des artères. *J. de chir. Paris* 9: 541-560, 1912.

(4) Moure, P.: Greffe vasculaire; preuve de la vitalité du greffon par une double greffe. *Bull. et mém. Soc. anat. de Paris* 88: 489-492, 1913.

¹⁰² (1) Lexer, E.: Die ideale Operation des arteriellen und des arteriell-venösen Aneurysma. *Arch. f. klin. Chir.* 83: 459-477, 1907.

(2) Warthmüller, Hans. Über die Bisherigen Erfolge der Gefäßtransplantation am Menschen. *Jena, G. Neuenbann*, 1917, p. 39.

¹⁰³ (1) Alessandri, R.: Chirurgia del cuore e Dei Grossi Vasi. *Cinq. Cong. de Soc. Internat. de Chir.*, Paris, 19-23 Juillet 1920, p. 139-241. Brussels, M. Hayez, 1921.

(2) Vön Bonin, G.: Aneurysmen durch Schussverletzungen und ihre Behandlung. *Beitr. z. klin. Chir. (Kriegs-chir. Hefte 2)* 97: 146-176, 1915.

(3) Hotz, G.: Zur Chirurgie der Blutgefäße. *Beitr. z. klin. Chir.* 97: 177-188, 1915.

(4) Renaux, L.: Reconstruction of Popliteal Artery. *Brazil-med.* 34: 509, 7 Aug 20. Abstract *J. A. M. A.* 75: 1756, 18 Dec 20.

(5) Sencert, L.: La Chirurgie des gros vaisseaux: 1. Les Blessures des vaisseaux. *Cinq. Cong. de Soc. Internat. de Chir.*, Paris, 19-23 Juillet 1920, p. 77-137. Brussels, M. Hayez, 1921.

(6) Zahradnický, F.: Die Behandlung der unechten Aneurysmen. *Wein. klin. Wchnschr.* 28: 999-1007, 1915.

(7) See also footnotes 95 (1) and (4), p. 110; and 102 (2), above.

¹⁰⁴ See footnote 102 (2), above.

¹⁰⁵ Matas, Rudolph: Military surgery of the vascular system. In Keen, W. W.: *Surgery—Its Principles and Practice*, by Various Authors. Philadelphia and London, W. B. Saunders Company, 1921, vol 7, p. 713-819.

¹⁰⁶ (1) Rehn, E.: Das Aneurysma der Arteria subclavia durch Schussverletzung und seine Ideal Operation mit freier Venenüberpflanzung. *Zentralbl. f. Chir.* 69: 1262-1275, 1 Aug 42. Abstr., *Bull. War Med.* 3: 264, Jan 1943.

(2) Rehn, E.: Grundsätzliche Bemerkungen zur rekonstruktiven Chirurgie des Schussaneurysma. *Zentralbl. f. Chir.* 70: 957-965, 3 Jul 43.

¹⁰⁷ Murray, G. D. W.: Heparin in thrombosis and embolism. *Brit. J. Surg.* 27: 567-598, Jan 1940.

¹⁰⁸ See footnote 100, p. 111.

¹⁰⁹ Schneider, H., and Bätzner, K.: Die Behandlung der Aneurysmen der Arteria poplitea und ihrer Äste. *Zentralbl. f. Chir.* 70: 965-975, 3 Jul 43.

¹¹⁰ Khenkin, V. L.: Experience in treatment of injuries of blood vessels in the forward area and at the rear. *Khirurgiya, Moscow* 2: 50-57, Oct 1944. Abstr., *Bull. War Med.* 6: 75, 1945-46.

¹¹¹ Tuffier: De l'intubation dans les plaies des grosses artères. *Bull. Acad. de méd.*, Paris 74: 455-460, Oct 1915.

¹¹² See footnote 3, p. 60.

reported 12 operations by this technique in 1922, 4 of which were nonacute lesions. One patient died of sepsis and another of gas gangrene, but results in the other cases were good. Makins also mentioned in this report Cowell's case, in which, when signs of gangrene followed ligation of a completely divided femoral artery, the limb was saved by removal of the ligatures and the use of a Tuffier tube. A number of other observers during this period reported favorable results with this method.¹¹³

Early in World War II British and Canadian surgeons attempted the use of glass tubes for arterial injuries, but their results are not known.¹¹⁴ Their potential clinical value was indicated by the successful experience of Murray and Janes¹¹⁵ in their experiments with heparin on dogs.

Plastic tubes were similarly used by American surgeons, though the results in the 14 cases in this series were not outstanding (Chart 15). Plastic prostheses have certain advantages over other prostheses in that they are apparently well tolerated by the tissues and can be altered in size and shape to fit the necessities of the special case merely by soaking the basic material in warm water. A supply of various sizes therefore need not be kept on hand. The technique of repair is simpler than when vitallium tubes are used, though the possibility of thrombosis is theoretically greater than when vein grafts are used.

Whether or not a permanent circulation is maintained through these tubes is not a matter of extreme importance if in the interim a collateral circulation has developed, since gradual occlusion of a vascular channel is always less deleterious than abrupt occlusion. This result cannot be achieved, however, unless operation is performed early, and the timelag offers an obstacle to this desideratum in most combat-incurred vascular injuries. The importance of some form of bridging of the arterial defect to permit at least a minimal circulation while collateral vessels are developing is illustrated by the following case report. Collaterals were adequate by the time the nonsuture graft thrombosed.

Case 9. This soldier, wounded by an enemy bomb fragment on shipboard off Southern France 18 August 1944, incurred a perforating wound of the right popliteal space with a laceration of the popliteal artery at its bifurcation into the anterior and posterior tibial arteries. He also received penetrating wounds of the right thigh and hand. There was no fracture. First aid consisted of morphine, tetanus toxoid, dusting of the wound with sulfanilamide powder, and the administration of sulfadiazine by mouth (2 gm. at once and 1 gm. every 4 hours). The following day, after the patient was transferred to a hospital ship, penicillin therapy was begun.

¹¹³ (1) Donati, M.: Ferite dei vasi sanguigni degli arti. *Chir. d. organ. d. mov.* Bologna 1: 191-254, 1917.

(2) Tuffier: A propos des plaies des artères. *Bull. et mém. Soc. de chir. de Paris* 43: 1469-1741, 1917.

(3) Tuffier: French surgery in 1915. *Brit. J. Surg.* 4: 420-432, Jan 1917.

(4) See also footnotes 3, p. 60; 13, p. 64; 95 (3), p. 110; and 103 (3), p. 115.

¹¹⁴ Matheson, N. M., and Murray, G.: Recent advances and experimental work in conservative vascular surgery. In *Bailey, Hamilton: Surgery of Modern Warfare*. Baltimore, Williams and Wilkins Co., 1941, vol 1, p. 324-327.

¹¹⁵ Murray, G., and Janes, J. M.: Prevention of acute failure of circulation following injuries to large arteries; experiments with glass cannulae kept patent by administration of heparin. *Brit. M. J.* 2: 6-7, 6 Jul 40.

When he was admitted to a general hospital in the base on 21 August his right leg was nearly twice normal size and the calf was tense. The toes and ankles were discolored and mottled. The foot was numb, cold to touch, and motionless as far as the ankle. The skin of the foot was mottled but blanched fairly easily. No pulsations could be felt in the leg or foot. There was moderate pain in the leg. The popliteal space was full but soft. Auscultation revealed a systolic bruit in this area; diastole was clear. The hematocrit value was 30 percent and the total plasma protein concentration 7.15 gm. per 100 cubic centimeters.

A transfusion of 1,000 cc. of whole blood was given and conservative treatment was decided upon for the time being.

The following day (22 August) there was a sudden, brisk hemorrhage from the small lateral wound behind the head of the fibula at the knee with an estimated loss of about 1,000 cc. of blood. Shock was moderate. Bleeding was controlled by the application of a temporary tourniquet which stopped the bleeding in 25 minutes. Seven hours after the hemorrhage the foot was ice cold, the mottled areas were more prominent, and it was apparent that in all likelihood the limb would not survive. The bruit in the popliteal space could no longer be heard. The hematocrit value was 35 percent and the plasma protein concentration 7.5 gm. per 100 cubic centimeters.

The vascular operation was preceded by lumbar ganglionectomy, with resection of the second, third, and fourth lumbar ganglia. When the right popliteal space was explored the gastrocnemius muscle herniated through the incision in the fascia. The fibers of the heads of the muscle were separated, very pale, and putty-like in consistency. Hematoma formation was evident beneath the heads. The tibial nerve appeared contused, but was intact. The popliteal vein had been severed, and the popliteal artery was also severed except for a narrow strand of the wall on the deep aspect which kept the ends from retracting. The artery was open for a distance of about $1\frac{1}{4}$ inches, including the area of its bifurcation. A thrombus was aspirated from the posterior tibial artery. The severed popliteal vein was ligated at each end, and a nonsuture anastomosis was done between the popliteal and posterior tibial arteries bridging a gap of about 2 inches. A segment of the left saphenous vein was used. The foot was warmer and of better color after operation than before. Heparin was not available.

The day after operation the entire right leg was edematous and there was some redness in the upper half of the leg. Both foot and leg were warm and blanched fairly well. The patient's temperature was 102° F. and his general condition was fair. A transfusion of 1,000 cc. of whole blood was given.

By 30 August, the sixth day after operation, the acute edema of the leg had subsided and the foot was warm. On the external lateral aspect of the heel was a small round area of discoloration. All sutures were removed from the right flank and left thigh. The wounds of the right popliteal space and right space were sutured. There was still a small amount of slough on the surface of the lateral head of the gastrocnemius, but beneath it was normal-looking muscle. The skin edges came together easily.

On 2 September an arteriogram with diodrast revealed no flow through the anastomosis but an excellent collateral circulation was demonstrable (Fig. 5). On 5 September faradic stimulation of the leg muscles was done. Reactions were obtained only from the gastrocnemius and posterior tibial muscles, but edema still present in the leg made interpretation of the negative results uncertain. On 6 September all sutures were removed. Healing was satisfactory. The foot was warm, pink, and dry. The small round spot of necrosis on the heel was thought to be the result of pressure while the posterior plaster shell was in place.

On 17 September the right calf was still indurated and enlarged. There was no motion in the toes but the patient had begun to feel tingling in the dorsum of the foot. There was anesthesia to 3 inches above the lateral malleolus and $1\frac{1}{4}$ inches above the medial malleolus. No further observations were possible after this date.



Figure 5. Laceration of popliteal artery treated by nonsuture anastomosis. Arteriogram 9 days after operation showing excellent collateral circulation. Thrombosis now blocks the anastomosis, which may have been patent earlier, however.

Comment. In this case ischemia which had been only partial for 3 days after wounding suddenly became complete and it seemed that the limb would not survive. The circulation improved following nonsuture anastomosis (vitallium tubes and vein segment), though an arteriogram 11 days after operation showed thrombosis of the anastomosis. It is quite possible, however, that the anastomosis was open earlier and that the temporary circulation which it afforded, together with the fact that for the initial 3-day period the ischemia was only partial, allowed the development of a collateral circulation which was sufficient to ensure survival of the limb.

Nonsuture Anastomosis

The principle of nonsuture anastomosis originally developed by Payr in 1900¹¹⁶ was tested experimentally by Höpfner in 1903¹¹⁷ and was successfully applied clinically by Lexer in 1907.¹¹⁸ Jeger, in 1913,¹¹⁹ advocated this method for military surgery but it does not seem to have been employed in World War I.

In 1942 Blakemore, Lord, and Stefko¹²⁰ in effect revived the technique of these earlier investigators as a method of restoring the blood flow through severed arteries. They used vitallium tubes, instead of the magnesium alloy tubes which Payr and Höpfner had used, lined them with vein grafts, and tied the cut ends of the artery over the ends of the connecting cannula. Somewhat later they modified their method, so that it resembled Höpfner's technique, by using two tubes bridged by a vein graft.

The results secured by Blakemore and his associates¹²¹ with this technique were so encouraging that hope was expressed that the method would be equally effective in military surgery. The vitallium tubes required became available in the Mediterranean theater in August 1944.¹²² They were in limited supply and therefore were used only in carefully selected critical cases cared for by experienced vascular surgeons.¹²³ It is known that the double-tube-vein-graft technique was employed in 40 cases (Chart 15).

Case 10. When this soldier was wounded by enemy machine pistol bullets 11 March 1945 near Lucia, Italy, he incurred penetrating wounds of the right upper arm, a compound comminuted fracture of the right humerus, a perforating wound of the right forearm with a compound comminuted fracture of the ulna, and a perforating wound of the right thigh where the femoral artery and vein were both divided in the adductor canal by the missile. The sciatic nerve was partially divided. The femur was not fractured. First aid consisted of sulfanilamide powder and dressings applied to the wound, 4.0 gm. of sulfadiazine given orally during evacuation, and 4 units of plasma. No tourniquet was applied. The patient reached an evacuation hospital 5 hours after injury. As preparation for operation he received 1 unit of plasma and 2,000 cc. of whole blood. At the conclusion of resuscitation the hematocrit value was 40.5 percent and the blood volume, determined by the T-1824 dye method, was high normal (6,160 cc. for a body weight of 68 kg.). The blood pressure was 144 mm. of mercury systolic and 100 diastolic.

¹¹⁶ Payr, E.: Beiträge zur Technik der Blutgefäße und Nervenennaht nebst Mittheilungen über die Verwendung eines resorbirbaren Metalles in der Chirurgie. *Arch. f. klin. Chir.* 62: 67-93, 1900.

¹¹⁷ Höpfner, E.: Über Gefäßnaht, Gefäßstransplantationen und Replantation von amputirten Extremitäten. *Arch. f. klin. Chir.* 70: 417-454, 1903.

¹¹⁸ See footnote 102 (1), p. 115.

¹¹⁹ Jeger, Ernst: Die Chirurgie der Blutgefäße und des Herzens. Berlin, Hirschwald & Co., 1913.

¹²⁰ Blakemore, A. H.; Lord, J. W., Jr., and Stefko, P. L.: The severed primary artery in the war wounded; a nonsuture method of bridging arterial defects. *Surgery* 12: 488-508, Sep 1942.

¹²¹ (1) Blakemore, A. H.; Lord, J. W., Jr., and Stefko, P. L.: Restoration of blood flow in damaged arteries; further studies on a nonsuture method of blood vessel anastomosis. *Ann. Surg.* 117: 481-497, Apr 1943.

(2) Blakemore, A. H., and Lord, J. W., Jr.: A nonsuture method of blood vessel anastomosis; review of experimental study; report of clinical cases. *Ann. Surg.* 121: 435-453, Apr 1945.

(3) Blakemore, A. H., and Lord, J. W., Jr.: A nonsuture method of blood vessel anastomosis; experimental and clinical study. *J.A.M.A.* 127: 685-691; *idem, ibid.*: 748-753, Mar 1945.

¹²² Later, an ordnance company copied the tubes in stainless steel and they were used with great satisfaction at the 8th Evacuation Hospital.

¹²³ See footnote 50, p. 99.

The operation, which was performed with the patient under ether-oxygen anesthesia with thiopental sodium induction, lasted 5 hours and 15 minutes. A primary incision was made in the femoral triangle and a tape was passed under the common femoral artery to permit emergency control of hemorrhage. All wounds were debrided. The femoral vein was ligated in the adductor canal. Anastomosis of the severed femoral artery was accomplished by means of stainless steel tubes fashioned after those described by Blakemore and his associates. A segment of the right long saphenous vein was used to bridge the gap.

Before the anastomosis was completed a clot was detected in the end of the artery just above the proximal tube. Heparin was injected subcutaneously (2 cc. in Pitkin's menstruum) and when the clotting time (determined by the Lee and White method) was 10 minutes, the clot was removed and the anastomosis was completed. Good pulsation was noted in the femoral artery distally, beyond the lower tube. The primary incision was closed, but the other wounds were left open for later delayed primary suture. No untoward effects followed procaine hydrochloride block of the third and fourth lumbar ganglia.

The patient's general condition during operation was satisfactory. The systolic blood pressure remained in the neighborhood of 120 and the diastolic between 70 and 80 mm. of mercury. The pulse rate ranged between 110 and 120 beats per minute. In the course of the operation the patient received 500 cc. of whole blood, 1,000 cc. of 2-percent sodium bicarbonate, and 1,000 cc. of 5-percent glucose in physiologic saline solution.

On 12 March, the day after the operation, the patient received 500 cc. of 2-percent sodium bicarbonate by vein and 1,000 cc. of whole blood. He was also given, subcutaneously, 2 cc. (200 mg.) of heparin in Pitkin's menstruum. Examinations of the urine showed a 2+ to 4+ reaction for benzidine-positive substance but no other abnormality. The sympathetic block was repeated.

The right foot was cooler than the left; the capillary circulation in the right foot was sluggish. There was neither sensation in the toes nor motor power in the left foot. When the effect of spinal anesthesia on the circulation of the leg was tested, the level of anesthesia reached the crest of the ilium. There was no immediate change in the temperature of the right foot.

A posterior fasciotomy was done from the popliteal space to just above the ankle. The gastrocnemius and soleus group of muscles bulged through the incision. They appeared edematous. There were areas of pallor in the gastrocnemius muscle but some pulsating vessels were seen in it. The soleus muscle was relatively more anemic. A small fasciotomy incision over the anterior tibial group of muscles revealed normal muscles with no bulging. After the posterior fasciotomy the foot appeared much improved in color; it was also warmer and the capillary circulation was better.

On 13 March the patient received 2 units of plasma and 1,000 cc. of whole blood. The foot was warm, the capillary circulation normal, and the posterior tibial pulse palpable and forceful. The dorsalis pedis pulse was not palpable. There was a moderate amount of serous drainage from the calf.

The patient received 2 units of plasma and 500 cc. of whole blood on 14 March. Two 2-cc. doses of heparin in Pitkin's menstruum (200 mg.) were given subcutaneously at 11-hour intervals. The foot and leg were edematous to the knee. The anterior tibial group of muscles, though rather tense, was resilient. Exudate continued to drain from the fasciotomy wound. The foot of the cot was elevated at half-hour intervals for 30-minute periods.

On 15 March the patient received 1 unit of plasma and 1,000 cc. of whole blood, together with 1 dose of heparin (2 cc.). Heparin thereafter was discontinued because the supply was exhausted. A unit of plasma and 500 cc. of whole blood were given the following day. Weak pulsation was felt in the posterior tibial artery and edema began to subside. Exudation from the fasciotomy wound also began to decrease. Two days later (18 March) both posterior tibial and dorsalis pedis arteries were readily palpable. Penicillin, which had been given daily in the amount of 200,000 units, and sulfadiazine, which had been given in 6-gm.

amounts, were discontinued. On 15 March the urine was free of benzidine-positive substance which had been present in small amounts since it first appeared 12 March. By 16 March the phenolsulfonphthalein excretory capacity of the patient was greatly improved. It had been 50 percent below normal on 12 March.

The patient was transferred to a general hospital on 19 March. When the dressings were changed in the operating room 22 March the gastrocnemius and soleus muscles showed some separating slough. All wounds were closed except the wound on the posterior thigh and the fasciotomy wound.

The hip spica was changed on 5 April and the sutures were removed. The fasciotomy wound showed superficial suppuration and a small amount of slough was still found separating from the gastrocnemius-soleus group of muscles near the tendinous portions. The right foot was warm, though not as warm as the left. The sole of the foot and the toes were anesthetic and hypesthetic. No motion was detectable in the toes or the ankle. An arteriogram showed complete patency of the anastomosis (Fig. 6A, B). When the patient was evacuated to the Zone of Interior 13 April he stated that he was beginning to "feel" a little motion in the toes and ankle, though none could be detected objectively.



Figure 6. (Case 10.) Laceration of femoral artery and vein treated by nonsuture anastomosis. A. Roentgenogram 25 days after operation, before injection of diodrast. B. Arteriogram after injection of diodrast into common femoral artery.

Comment. The result in this case would probably not have been as satisfactory if the severed blood vessel had not been repaired by anastomosis. The appearance of a benzidine-positive substance (probably myoglobin) in the urine for several days after the operation is of interest in that it may indicate relief of ischemia. It is a physiologic fact that this substance does not appear in the blood and urine until the circulation has become reestablished.

The proportion of amputations for the double-tube-vein-graft technique was significantly higher than for suture repair. However, the difference was not considered to be due to the techniques used but to the different characteristics of the injury for which the type of treatment was selected.

Case 11. When this 22-year-old soldier was wounded by enemy rifle fire 19 September 1944 in Italy, he incurred a severe wound of the left knee with a compound comminuted fracture of the left femur extending into the knee joint. The popliteal artery and vein were completely transected in the midpopliteal space. When the patient was admitted to an evacuation hospital 20 September, 9½ hours after wounding, the blood pressure was unmeasurable. He had already received 2 units of plasma. Three hours later, after resuscitation with whole blood and plasma, the blood pressure was 104 mm. of mercury systolic and 58 diastolic.

The operation was performed 14½ hours after injury with the patient under thiopental sodium anesthesia. The wound was debrided, the popliteal vein ligated, and the popliteal artery suture-ligated. A lumbar sympathetic block was done at the conclusion of the operation and was repeated 8½ hours later (1.5-percent procaine hydrochloride was used). No improvement was noted after either block.

On 21 September the left foot and leg were cold up to the level of the tibial tubercle. Areas of purple discoloration on the dorsum of the foot and in and around the great toe did not blanch. No pulsations could be felt in the foot or at the ankle. No oscillations were observed in the calf. The foot was anesthetic to just above the ankle. There was no motion in the toes. Although little hope was felt for preservation of the extremity it was decided, as a last resort, to do a nonsuture anastomosis with the hope of improving the circulation sufficiently to save part of the leg. After transfusion of 500 cc. of whole blood a left lumbar ganglionectomy was done, with excision of the second, third, and fourth ganglia. The ends of the popliteal artery were exposed and anastomosis by the nonsuture technique was performed (Fig. 7A). Vitallium tubes and a segment of the right long saphenous vein were used. A gap 2 inches long was thus bridged (Fig. 7B). A posterolateral fasciotomy was done in the calf. A bivalved cast was applied, using only the posterior half. Intravenous administration of heparin was begun at once at the rate of 600 mg. every 24 hours, and the foot was kept in a dependent position.

The day after operation there was no edema of the foot; the foot was, however, cold and anesthetic to just above the ankle. There was no motion in the toes or at the ankle. The calf was swollen to almost twice normal size. A transfusion of 1,000 cc. of whole blood was given. On 24 September the appearance of the left calf was unchanged. During the previous 48 hours the area from the level of the tibial tubercle to about 6 inches above the malleoli became warmer. The foot was cold and dusky and the terminal phalanges of the toes were purple. The following day the foot was cold but the calf was warm to within 3 inches of the malleoli. The clotting time (by the capillary tube method) was 22 minutes.

By 27 September, the seventh day after injury, when no improvement in the condition of the limb had occurred (Fig. 7C), amputation was recommended. It was carried out the following day, with the patient under ether anesthesia. An attempt was made to perform the amputation at the midleg, but at this level, while there was bleeding from the skin, there was none from the muscles. Upon examination the muscles proved to be pale and nonviable (Fig. 7D). Amputation was therefore done at the supracondylar level. Recovery was uneventful.

Comment. When the anastomosis was exposed in the amputated specimen both the cuffs were found in place but the artery was thrombosed proximal to the anastomosis. Thrombosis extended distally into the leg and the venous segment was filled with blood clot. The anastomosis in this case was probably of no value because it was done after extensive thrombosis had occurred in the leg.

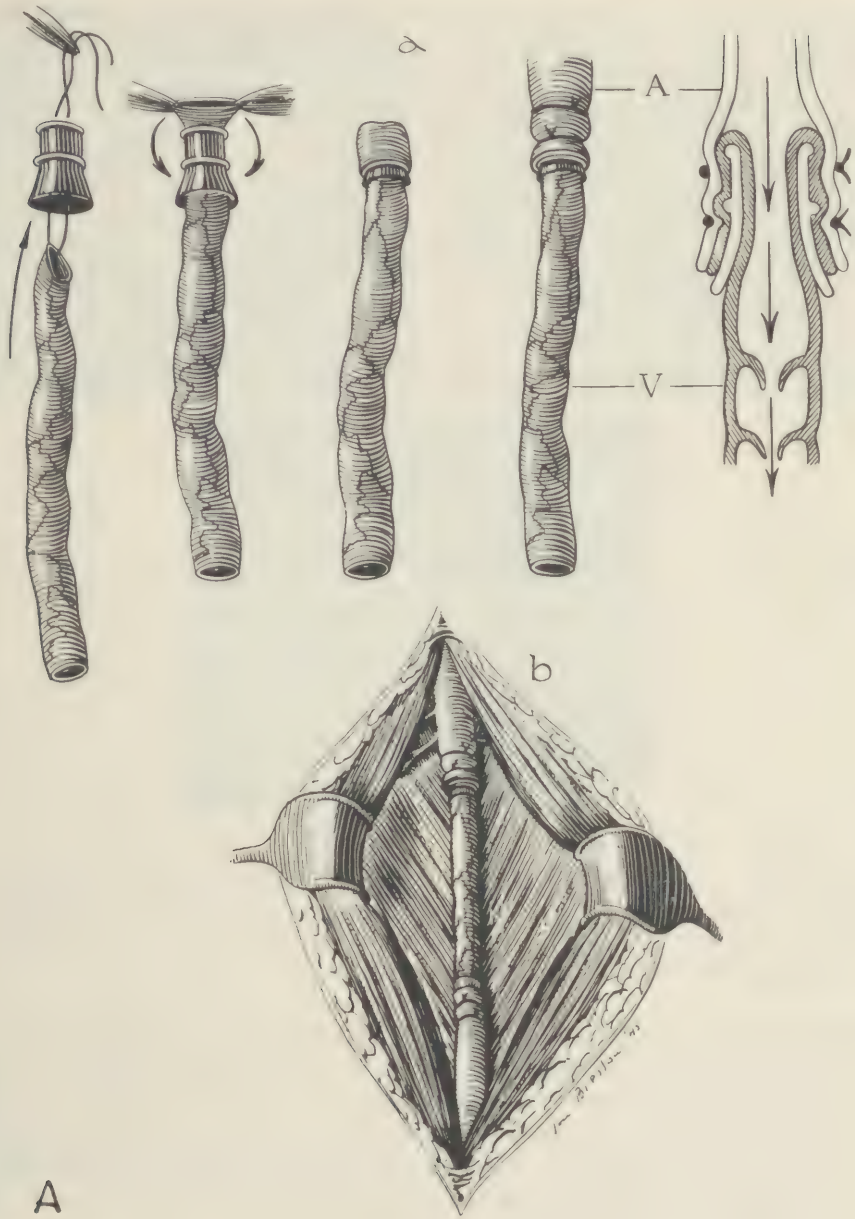


Figure 7. A. Details of nonsuture technique. a. Method of making anastomosis, this is essentially the technique described by Blakemore, Lord, and Stefko, except that the vein is not ligated onto the tube. Note that one of the ties is looser than the other and that the direction of the valves in the vein is reversed. b. Completed anastomosis.



Figure 7—Continued. *B. Transection of popliteal artery treated by nonsuture technique. The arterial injury was complicated by a severe compound fracture of the tibia and the dislocated tibial fragments are still attached in the wound. C. Appearance of foot 7 days after anastomosis. D. Dissection of amputated leg. The muscles were pale and swollen and the subcutaneous tissues were edematous.*

In 8 of 13 cases observed in Italy (9 of which one of us personally operated on) amputation was necessary later, in 1 instance limited to the toes, in 2 through the lower leg, and in 5 through the thigh. All of these patients had severe injuries and it is doubtful that the limbs could have been saved under any method of treatment. The cases were deliberately selected for trial because the use of this method under battle conditions was considered purely experimental and therefore justified only in critical cases.

All of the patients in this series, as just noted, had severe injuries. In 3 of the 5 cases in which amputation had to be done above the knee, severance of the popliteal artery was complicated by a compound fracture of the knee joint. While it must be granted that this is the type of case in which experience has shown that survival of the limb is unlikely, it must also be emphasized

that this is exactly the type of case in which it was hoped that nonsuture anastomosis would improve the results if it could be done early enough for diffuse thrombosis and infection not to have become established.

Failure in 2 cases in the series just mentioned could be attributed to technical errors. In 1 instance re-anastomosis after bleeding from a tiny venule had become apparent was not successful because peripheral thrombosis had already developed. In the other case the edge of the vitallium tube cut through the arterial wall on the 11th day after operation. When the anastomosis was performed there had been a good deal of difficulty in inserting the tube into the lumen of the vessel.

What is more important from the standpoint of military surgery than the exact results secured in this series is the character of the technique. The ease or difficulty with which an operation can be performed is an important consideration in military surgery, and the experience in World War II suggested that nonsuture anastomosis is neither as simple nor as easy as its proponents, whose extensive experience with the method was confined to civilian practice, indicated that it was. One operation in Italy, for instance, performed by a better-than-average surgeon, took 3½ hours; in the course of the procedure the ligature twice slipped off the tube and had to be tediously reapplied. A forward hospital, when casualties are heavy, is not the place for such time-consuming surgery if it produces no better results than can be secured by other, simpler methods. It is not known how many times the method was attempted and failed, though this is known to have happened 5 times in a series of 23 cases. Another possible disadvantage of the method is that when it is not successful it may result in the destruction of additional arterial substance. This is a particularly undesirable result and the sacrifice of functional collateral arteries was felt to be a definite contraindication to the use of the method in any case in which there was not a reasonable chance of success.

It must be granted that although these operations were done by capable surgeons, they involved a new technique, and better results can probably be expected as experience increases.

The various series of reparative operations performed for acute arterial injuries in World War II were all too small to permit definite statements concerning the value of any one of these methods as compared with other methods (Charts 15, 16). In individual cases it is possible to say that one method or another was responsible for the saving of all or part of a limb, but the overall figures permit no such conclusions. It must be emphasized again, however, that most of the cases in these series were cases in which, because of the size of the defect, suture repair was not practical, in which the proportion of critical vessels was high, and in which the prognosis was always grave.

Sympathectomy was usually performed when a major artery of the lower extremity had been treated by nonsuture anastomosis.

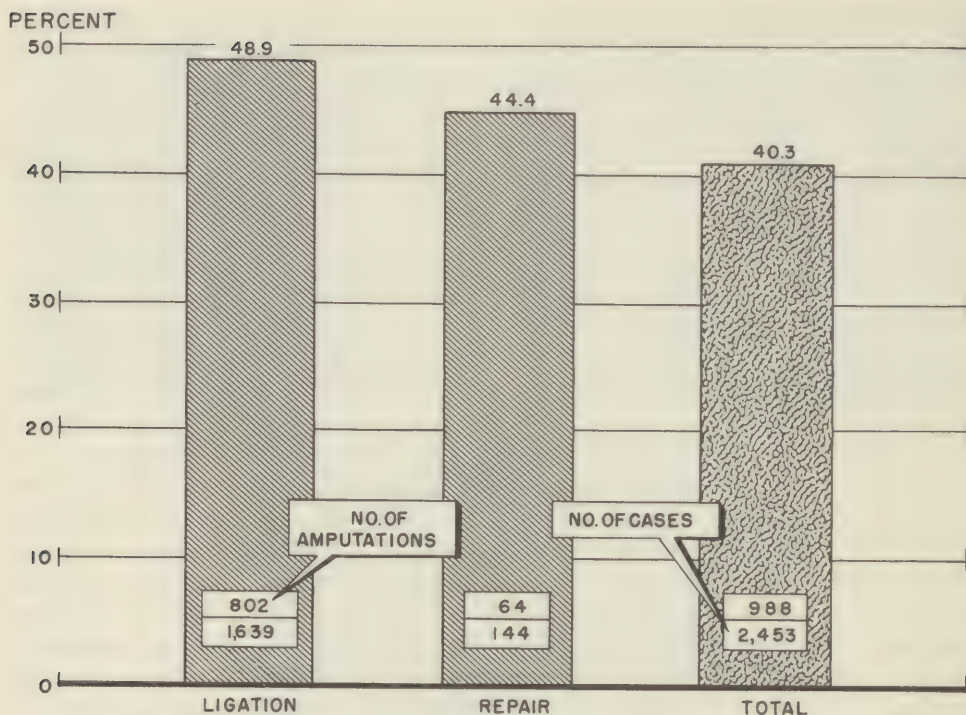


Chart 16. Incidence of amputation in arterial wounds in American battle casualties in World War II according to method of management. The data depicted are based on a selected group for which the necessary information was available. They do not include all arterial wounds during World War II. The difference between total cases and breakdown in this chart represents 670 cases for which therapeutic measures could not be determined or are not included in the two categories. Type of repair was not known in 9 cases, of which 5 involved amputation, and these are not included in the types of repair shown in Chart 15.

COMPLICATIONS OF ACUTE ARTERIAL INJURIES

Ischemia

As the war progressed disastrous effects of circulatory constrictions, no matter what the cause, became recognized more and more. Constriction might be caused by action of the missile itself, by bacterial toxins and proteolysis, by vasospasm, and by effect of compound fractures or multiple injuries which impaired circulation directly or indirectly. Unwisely applied emergency measures were an unfortunately frequent cause. They included application of tight bandages, tight packs (particularly in deep wounds), tourniquets, and plaster casts. Plaster casts were particularly dangerous when applied under conditions which did not permit close observation of the patient afterward or when the cast had not been bivalved to allow for subsequent swelling of tissues. Dangerous ischemia could follow either localized or homogeneous compression.

A circular bandage inside a cast could give rise to dangerous ischemia and simple linear incision of a circular cast did not provide sufficient safeguard against edema of the limb and embarrassment of the circulation. Even prolonged elevation of a limb with a vascular injury might hasten ischemia which was impending or accentuate the condition if it had already developed.

Exactly why, when all circumstances seemed comparable, some wounds healed without complications, and in others local infection and gas gangrene developed, was never clearly understood. What was understood, however, was that certain factors favored the growth of clostridia and enhanced the development of infection, and that loss or impairment of circulation in the involved tissues was the most important of these causes.

Eventually these dangers were warned against in directives issued in the Mediterranean¹²⁴ and European theaters,¹²⁵ and the Office of The Surgeon General.¹²⁶ One of the precautions against the development of serious ischemic complications was retention of a patient with an injured extremity at the evacuation hospital whenever the blood supply seemed to be jeopardized. He was not permitted to be evacuated further until it was clear that the collateral circulation was adequate or until amputation had been performed.

Pulsating Hematoma

Although aneurysms and arteriovenous fistulas seldom required treatment in forward hospitals, false aneurysms (pulsating hematomas) were in a different category.¹²⁷ Many surgeons took the position that the risk of hemorrhage or rupture was so great in this type of lesion that evacuation to the Zone of Interior was unsafe until operation had been performed. In theory, this was a complication which could be prevented by proper treatment of vascular injuries. In practice, planned repair of the arterial defect was often not possible because of the circumstances of war. Frequently, extensive damage to muscles, nerves, and bones did not even permit an exact determination of the vascular damage.

Pulsating hematomas were usually encountered in cases in which it was not possible to ligate the main vessels securely and immediate hemorrhage had to be controlled by packing. They were also encountered in cases in which, because the wound was small and there was little external loss of blood, massive hemorrhage into the tissues had occurred and had been overlooked. In some cases infection and necrosis produced secondary hemorrhage into the limb, which was not obvious externally. In all such cases the blood extravasated into the part and clotted. Later, if the condition was not remedied, a true endothelial sac was partially or completely organized. Expansile pulsation could be observed as long as blood continued to enter the mass. When the area had become over-distended and no further blood could enter the sac, all

¹²⁴ See footnote 22 (3), p. 70.

¹²⁵ See footnote 89 (3), p. 108.

¹²⁶ (1) Gas gangrene prophylaxis. Bull. U. S. Army M. Dept. 75: 26-28, Apr 1944.

(2) See also footnote 29, p. 81.

¹²⁷ See footnotes 22 (3), p. 70; 23, p. 71; 29, p. 81; and 89 (2), p. 108.

pulsation ceased. This was the time during which the blood supply to the limb could be totally occluded both by an intraluminal clot and by secondary compression of the artery. As a result the part below the lesion began to swell and the patient complained of pain, or of more pain if pain had already been a feature of his clinical course.

While a pulsating hematoma could develop at any time following injury, it most often became evident within the first 2 to 8 weeks. It was also particularly easy to overlook it during this period because the patient was being transported to the rear, and examinations along the way were apt to be superficial. If the limb was in a cast, examination was frequently omitted.

The diagnosis of pulsating hematoma usually was not difficult if it was remembered that it was a possibility in any instance of penetrating trauma in the vicinity of large arteries, and that the possibility was strong if there was a history of initial profuse hemorrhage, or if an initial hemorrhage had had to be controlled by packing. When the packing was removed, a cavity often remained which was an ideal site for the escape of blood. Undue swelling of the part and pain and discomfort, especially after a change of cast, were always indications for careful local examination. Characteristically, the pain was out of proportion to that previously experienced. Sometimes a mass was not palpable, but if hemorrhage had occurred recently, or if rupture was impending, it usually was present and might be of considerable size. If the sac was well developed, pulsations could be seen and were likely to be associated with a systolic bruit.

Differentiation of a pulsating hematoma from an abscess offered the chief diagnostic problem. If the hematoma was well developed and presented the classical signs there was seldom any difficulty. Otherwise, the differentiation had to be made on the basis of the systemic manifestations likely to be present in abscess formation. It was a sound rule not to incise a fluctuant mass near a blood vessel, even though evidence of infection was present, until the possibility of pulsating hematoma had been eliminated.

In small pulsating hematomas which had become infected, an occasional spontaneous cure followed the occlusion of the affected vessel by the so-called currant-jelly clot and subsequent fibrosis:

Case 12. A 36-year-old soldier wounded by aerial bomb fragments at Anzio, Italy, 28 January 1944, incurred multiple penetrating wounds of the left hand, left wrist, and both thighs. The right femoral artery was involved in the wound on that side. The wounds were debrided at an evacuation hospital the same day, and a foreign body was removed from the left thigh.

Roentgenograms taken at a general hospital 3 February showed metallic fragments in the upper third of the right thigh; there was an incomplete fracture of the femur in the same area. A moderately low-pitched bruit (systolic) and an expansile pulsation could be demonstrated just proximal to the middle of the right thigh medially. The bruit did not have a "machinery" quality. There was no evidence of nerve damage and the pulses in the right foot were normal. The erythrocytes numbered 3,280,000 and the leukocytes 19,600 per cubic millimeter of blood. Transfusions of 500 cc. of whole blood were given 5 February and 9 February.

On 11 February all wounds were closed secondarily, and subsequent healing was satisfactory. At this time the patient was complaining of periods of numbness in the dorsum of the right foot. The following day the systolic bruit over the left femoral artery was recorded as softer and less shrill. It was still present on 14 February, but on 15 February when the patient was shown to a surgical consultant to secure advice concerning the management of the aneurysm, there were no signs of the lesion nor was there any further evidence of its presence during the week the patient subsequently remained under observation.

Comment. The case demonstrates one of the advantages of delaying the surgical treatment of traumatic aneurysms and similar lesions, for sometimes, as in this instance, they disappear spontaneously.

In most cases of pulsating hematoma observed in World War II, surgery was necessary, though it was best postponed for 2 to 3 months if pain or evidence of impending rupture did not furnish indications for immediate operation. The longer an operation could be postponed, the more likely was the collateral circulation to be adequate. It was also desirable that the external wound be well healed and that dormant infection be excluded before operation was undertaken, but this was not always possible in the absence of a well-organized sac. When such a sac was not present, copious bleeding often followed necrosis or slough of extensive soft-tissue wounds and even disruption of recently sutured wounds. In these cases, when pallor of the limb, absence of pulsations distal to the lesion, swelling of the part, or lowering of the surface temperature indicated that the blood supply to the extremity was reduced, it was not safe to postpone operation.

The most important technical step in operations for pulsating hematoma was control of bleeding from above; a dry operative field was imperative. Frequently this could be achieved with a properly applied tourniquet, though in wounds of the upper thigh this was not possible. A safer method in all cases was to expose the main vessels above the lesion and to ligate them temporarily with rubber bands or tape. An approach through the original wound was usually complicated and unsatisfactory. True arteriorrhaphy or endoaneurysmorrhaphy was not always the wisest procedure, or, indeed, a feasible procedure. The rent in the vessel was frequently too extensive and the separation of the ends too great. Segmental defects in the wall were also frequent. The best plan, after evacuation of the sac, was occlusion of the proximal and distal portions by interrupted silk sutures carefully placed in the ends of the vessel, or by ligation. The temporary bands occluding the blood supply were then loosened to make sure that occlusion was complete. The cavity was lightly packed with gauze and adequate drainage was provided in all cases since most of the wounds were infected. Primary closure was always contraindicated if the operation was done on the indication of rupture or threatened rupture.

Secondary Hemorrhage

Secondary hemorrhage was a relatively frequent complication of arterial injuries in World War I. In a series of 10,000 patients with wounds in which

the long bones were involved, Waugh¹²⁸ observed an incidence of 14 percent in 1 year and of 9 percent in the following year. He attributed the improvement in the second year to "improved arrangements for the early excision of wounds." Tuffier,¹²⁹ in commenting upon secondary hemorrhage from arterial wounds during the First World War, also related the incidence of the complication to the incidence of infected wounds.

In World War II the incidence of secondary hemorrhage was strikingly reduced because of improvements in the technique of debridement and immobilization, and the availability of chemotherapeutic and antibiotic agents. Of these reasons, improvement in debridement and the use of chemotherapeutic and antibiotic agents were probably the most important because of their beneficial effect on the incidence of wound infection. The problem was still important, however, because of the disastrous consequences which might follow severe bleeding.

In all theaters the practice of delay in operation for aneurysm and arteriovenous fistula probably had much to do with reducing the incidence of secondary hemorrhage. It was generally taught that secondary hemorrhage was a possibility, even if a remote one, when arterial or venous ligation was undertaken, and it was recommended that a tourniquet be kept in position about the limb to be tightened immediately if hemorrhage should arise which could not be controlled by simpler measures. In an occasional case the loosening of thrombi several weeks after their original formation resulted in secondary hemorrhage.

In the North African Theater of Operations not a single secondary hemorrhage was encountered in forward hospitals in the Sicilian campaign, perhaps because the patients were seldom kept long enough for it to occur. On the other hand, the basic reason probably was that the wounds were not particularly extensive.

The secondary hemorrhages encountered in the Italian campaign and studied by Capt. J. T. Coyle and Maj. W. D. Thompson¹³⁰ were of two types. The first and more frequent type occurred from large muscle areas when a thin layer of necrotic material sloughed en masse. It was readily controlled in every instance by thoroughly cleaning out the slough tissue and applying hot, moist sponges. Petrolatum impregnated dressings were not satisfactory; dry gauze fluffs, removed after 48 hours, worked well. The second type of hemorrhage occurred from large wounds of the calf after sloughing of the wall of the posterior or anterior tibial artery. It was controlled by ligation of the involved artery and no circulatory disturbances were noted subsequently in any of these patients.

¹²⁸ Waugh, W. Grant: Secondary hemorrhage. In Bailey, Hamilton: *Surgery of Modern Warfare*. Baltimore. Williams & Wilkins Co., 1941, vol 1, p. 328-332.

¹²⁹ See footnote 113 (3), p. 116.

¹³⁰ Coyle, J. T., and Thompson, W. D., Jr.: Fractures in battle casualties. *Bull. U. S. Army M. Dept.* 86: 57-63, Mar 1945.

The experience reported by Lt. Col. Norman E. Freeman¹³¹ at the 20th General Hospital at Assam, India, may be taken as typical of the World War II experience with secondary hemorrhage. This complication was observed in 23 of 2,168 patients treated in the course of a year for gunshot or shell wounds of the extremities and neck. In 8 of these patients bleeding was from small vessels and was readily controlled by packing or by simple ligation of the bleeding vessel in the wound. In the other 15 patients hemorrhage was from a major vessel and was a serious problem. Freeman personally operated on 12 of the 15 patients and supervised the treatment of 2 others, which makes the report of this particular experience of unusual value.

Clinical Observations. In every instance in Freeman's series the wound was located in the immediate proximity of the vessel from which the hemorrhage occurred, a circumstance which naturally simplified the diagnosis. As in Waugh's series,¹³² compound fractures were present in more than two-thirds of the cases. Another observation of major importance, though its significance was not always realized, was that the patients in whom secondary hemorrhage occurred had (1) a previous clear-cut story of massive hemorrhage or recurrent bleeding while in the forward area, or (2) a condition of severe anemia at the time of admission to the hospital. Eventually it was realized that injury to a large vessel should always be suspected when a heavy loss of blood was evident. In 7 patients one or more episodes of bleeding occurred before the final massive hemorrhage. Failure to heed this "red signal" was responsible for the death of 1 patient (Case 13) and would have been responsible for death in others except for the skilled intervention of ward personnel (Case 14). As emphasized by Waugh "a small initial hemorrhage occurs in more than half the total cases and constitutes an inexorable indication for exploration of the wound." This lesson was eventually learned in World War II and ward personnel were instructed to report immediately any bleeding, however small.

Case 13. A 27-year-old Chinese soldier was struck just below the left shoulder by a bullet from a .25 caliber pistol on 1 March 1944. The wound of entrance was over the lateral surface of the left arm below the acromion and the bullet came to rest in the soft tissues of the axilla. A compound fracture of the humerus was present in addition to the soft-tissue injuries. Débridement had been performed in the forward area and a plaster encasement applied to the left shoulder with the arm in abduction. When the patient reached the 20th General Hospital the radial pulse was normal, normal sensation and motion were present in the fingers, and there was no edema of the extremity. The value for hemoglobin was 8.8 gm. per 100 cc. of blood. When the cast was changed 14 March the wound appeared clean and there had been nothing in the patient's progress to suggest subsequent difficulties. A hanging plaster encasement was applied to the forearm for traction and a separate spica was applied to cover the wound.

On 17 March the Officer of the Day noted on the patient's record at 0700 that some bleeding had occurred for a few minutes under the encasement while the man was brushing his teeth, but that it had stopped and his condition was good though he would probably

¹³¹ Freeman, N. E.: Secondary hemorrhage arising from gunshot wounds of the peripheral blood vessels. *Ann. Surg.* 122: 631-640, Oct 1945.

¹³² See footnote 128, p. 130.

need a new encasement. Six hours later the ward officer noted that there had been no further bleeding, that the patient's condition was satisfactory, and that it could be seen under the encasement that the wound was dry. Two and one-half hours later there was a second small episode of bleeding and the patient vomited and fainted. When the ward officer removed the encasement, the wound was dry. A corpsman reported that he had seen the patient "picking at the wound with his chopsticks," and it was assumed that this action had caused some bleeding from the granulations.

For the next 10 days progress was completely satisfactory except that, for the first time, the patient had a higher than normal temperature. There was no bleeding and the alignment of the fracture was satisfactory. On 27 March, 27 days after wounding and 10 days after the episodes of bleeding, the patient suddenly screamed. He was found sitting up in bed in a pool of blood and death occurred while the encasement was being cut off and efforts were being made to start a transfusion.

Case 14. A Chinese soldier sustained a shell fragment wound just below the angle of the left mandible 18 March 1944. The missile lodged in the transverse process of the first cervical vertebra. Debridement was performed in the forward area and was accompanied, according to the operative note, by "much bleeding." Three days after the patient's admission to the 20th General Hospital, and 4 days after he had been injured, a swelling was noted below the left mandible which continued to increase in size and to cause severe pain. His temperature was normal. On 30 March, 12 days after the original injury, with a preoperative diagnosis of cervical abscess the mass was incised. The "rush of blood" which ensued was controlled with difficulty by suture of the skin and a pressure dressing. On 7 April, 8 days later, a pulsating tumor with a palpable thrill and continuous murmur was found below the lobe of the left ear. The wound was healing but serous fluid was weeping from the skin edges. The anterior jugular vein was distended when the patient was recumbent but collapsed when he sat up. The pulse rate dropped from 72 to 60 beats per minute when pressure over the carotid artery was sufficient to abolish the murmur. A diagnosis of arteriovenous fistula was made.

In this case it was considered desirable, if possible, to allow complete healing to occur before the fistula was excised. The delay was regarded as safe since hemorrhage from an arteriovenous fistula is rare because of the free communication with the venous side of the circulation and the resultant low pressure within the aneurysmal sac. A tight bandage was applied over the lesion, a procedure which, in retrospect, was realized to be a mistake since compression of the tissues, if it achieved anything, was likely to raise the pressure in the aneurysm because of pressure on the venous outlet.

The day after the bandage was applied, the nurse on the ward heard the patient cry out. When she went to him she found him sitting up in bed with blood streaming from his neck. She immediately applied digital pressure, thus controlling the bleeding and saving his life. As soon as possible he was transported to the operating room where, with the aid of local analgesia, the external carotid artery was exposed below the digastricus. The circulation was temporarily occluded by a rubber tube. The arteriovenous fistula was then opened and excised with quadruple ligation of the component arteries and veins. The hemorrhage had originated from the external maxillary artery and the temperomaxillary vein.

It is noteworthy that hemorrhage was sometimes preceded by minor activity such as brushing the teeth or moving the arms; however, in other instances it occurred without warning. In any event, such warnings as did occur were often so slight that they were ignored; moreover, the cessation of the initial hemorrhage induced an unwarranted sense of security.

In 3 of Freeman's patients bleeding into a cast hindered both diagnosis and treatment. Plaster encasement was an essential form of treatment in

both fractures and extensive soft-tissue injuries, but care was not always taken to exclude injuries of major blood vessels before immobilization was instituted.

In World War I secondary hemorrhage most often occurred between the 10th and 16th days after injury. In Freeman's series the range was from 2 days to 3 months. In 10 of the 15 cases he cited, the bleeding occurred within the first 2 weeks after wounding.

When these cases were reviewed it was found that physical examination at the time the patients were admitted to the hospital had not been helpful. Although all of the patients had lacerations of major arteries, as their clinical course later proved, the peripheral pulses were absent in only 2 and were diminished in only 2 others. Most of the patients presented peripheral edema or complained of a sense of numbness of the distal part of the affected extremity. In 2 patients, although the fingers were warm and the radial pulses palpable, tissue damage had obviously occurred and could have been caused only by severe ischemia of long duration. Since the circulation was adequate at the time of admittance, the observation pointed to a serious arterial injury for which compensation had been provided either by resumption of the blood flow through the injured vessel or by development of a collateral circulation.

In 4 instances a hematoma was present over the injured vessel, but a systolic bruit was audible in only 2 of these cases. In 4 other cases, although the initial examination was conducted with the possibility of an arterial lesion in mind, no bruit could be heard.

Character of Injuries. In 14 of the 15 cases in Freeman's series the arterial injury was a laceration. In the 15th case the vessel was only partially divided. Injuries of this type are much more likely to lead to severe bleeding than is complete severance in which retraction of the severed ends is a physiologic means of controlling hemorrhage. Waugh,¹³³ in his study of secondary hemorrhage in World War I, cited Makins to the effect that in every secondary hemorrhage an incomplete injury of a blood vessel is preexistent. These cases help to prove that thesis.

Therapy. In hemorrhage from minor vessels, as already noted, packing of the wound with dry gauze, the application of pressure, or ligation of the bleeding vessel in the wound was sufficient for control. Immediate arrest of bleeding, by one means or another, was the proper method of treatment in all cases and management included immediate replacement of the blood loss and arrangements for immediate operation. In the meantime the bleeding was controlled by emergency methods, with a tourniquet the last resort. In small wounds of the neck digital compression might be the only possible method of temporary control.

The first principle of surgery was that the incision be long enough for adequate exposure, since circulation through the afferent artery had to be controlled before the bleeding point could be found. There was never any

¹³³ See footnote 128, p. 130.

hesitation in opening and exposing the original wound. It was sometimes difficult to find the laceration when the bleeding had been checked by temporary measures, for the laceration was often sealed again by clot formation, and the circulation was depressed from loss of blood. In 5 of the 15 cases cited by Freeman manipulation was necessary to produce bleeding before the injury could be identified. It was essential to be quite certain that the precise source of the bleeding had been found. In 1 patient a small arterial branch of the popliteal artery was thought to be responsible, but recurrent hemorrhage after transfusion necessitated a second exploration and disclosed a laceration of the popliteal artery itself.

In 1 patient proximal ligation through a separate incision was performed for secondary hemorrhage after previous ligation of the femoral artery. After the vessel had been exposed, bleeding was controlled by rubber tubes placed proximally and distally and the bleeding point was then sought, in a dry field, without danger of injury to accompanying nerves and other structures.

Suture of the laceration was attempted twice but was successful in only 1 case. In the other, a ruptured false aneurysm of the femoral artery, amputation was required 6 days later for ischemic gangrene. In all the other cases the vessel was ligated and divided.

Case 15. In this case a shell-fragment wound, 11 July 1944, resulted in a supracondylar fracture of the left femur with little hemorrhage. When the patient was examined at the 20th General Hospital 12 July, the left foot was warm and the dorsalis pedis pulse was palpable. Skeletal traction was applied. Infection of the wound followed and was associated with intermittent fever. Pitting edema of the foot was noted about 4 weeks after injury. On 15 September, 2 months after injury, about 100 cc. of serosanguineous material containing some small clots was discharged from the wound immediately after the patient had used a bed pan. Distortion of the thigh was noted and roentgenograms confirmed the clinical impression of displacement at the fracture site. The ankle pulses were normal, motion and sensation were present in the toes, and there was no pulsation, thrill, or bruit over the femoral vessels just above the knee. One week later an accumulation of pus on the posterolateral aspect of the lower thigh was drained. Slight amounts of blood continued to appear on the dressings. The medial wound was now almost healed.

On 8 October, almost 3 months after the original injury, a brisk hemorrhage occurred from the posterolateral wound. It was controlled by packing until the patient could be taken to the operating room. Then, with the aid of spinal analgesia, the femoral artery was exposed in the adductor canal, the circulation was controlled, and the site of bleeding was sought. It proved to be a ruptured false aneurysm. Release of the distal end of the artery allowed no back bleeding. The laceration in the femoral artery was sutured since it was felt that the collateral circulation was insufficient. Pulsation of the artery below the line of suture took place after release of the upper rubber tubing applied to control the blood supply. After operation there was marked ischemia of the tissues below the knee.

Although the lower leg was refrigerated for 5 days, no improvement was evident and amputation through the fracture site had to be performed 14 October. Dissection of the arteries of the leg revealed that thrombosis had occurred below the point of suture.

Although Reid ¹³⁴ had condemned chromic catgut for these purposes, especially when wound infection was present because its absorbable properties

¹³⁴ Reid, M. R.: Partial occlusion of the aorta with silk sutures, and complete occlusion with fascial plugs; effects of ligation on the arterial wall. *J. Exper. Med.* 40: 293-299, Sep 1924.

made rapid disintegration likely, it was used in the series reported by Freeman without any untoward results. The factors of safety were probably adequate drainage and the use of sulfonamide drugs.

After operation alcohol was injected into the region of the paravertebral sympathetic ganglia in 4 patients with good results. In a fifth patient, procaine was injected repeatedly. In the case just described in which ischemic gangrene required secondary amputation, alcohol injection was not employed.

Vasospasm

Vasospasm is well known in civilian practice as accompanying wounds or manipulations of the arteries. It is, in fact, a natural response to any form of trauma which directly or indirectly affects the vascular structures. It was therefore a common occurrence in the arterial injuries observed in World War I as well as in those observed in World War II. Depending upon a number of factors it might involve only a small part of a vessel (as in arterial concussion), might spread to neighboring vessels, or might become sufficiently generalized to involve the entire limb and even larger areas of the body. Although vasospasm could under certain conditions be considered a compensatory mechanism, prolonged vasospasm could lead to serious consequences. When it was minimal, amounting merely to a localized area of constriction, the resulting ischemia was minimal and the limb was seldom placed in jeopardy. When it was more extensive, and especially when the collateral circulation was involved, ischemia was often sufficient to produce localized gangrene. When it occurred in cases in which trauma to the tissues had already seriously impaired their vitality, vasospasm was often the factor which determined whether the limb would survive or die. An additional factor of danger was that the results of ischemia might cause development of gas bacillus infection.

In the category of spasm are included the few cases of contusion recorded as such in American battle casualties in World War II because this condition, if it was recognized at all, was not infrequently accompanied by spastic phenomena. This type of lesion was usually slight and its inclusion in a tabulated series therefore alters the results favorably. (This is perhaps one reason why Makins' statistics, in which contusions were included, are so much more favorable than other statistics from which they are omitted.) Some doubt is felt about the incidence of amputation (25 percent) reported in the 28 cases of spasm in this series (Chart 12). That the figures are weighted is suggested by the fact that in 1 sample of 6 cases, there were 5 instances of gangrene. This is so contrary to the usual experience as to suggest that the diagnosis of spasm was probably not correct in 1 or more cases in the group. Furthermore, most cases of spasm were not recorded at all and reports therefore included only those which developed complications.

Vasospasm, as the following cases show, might be transient or might be of long duration.

Case 16. A soldier wounded in Tunisia 31 March 1943, incurred a perforating shell-fragment wound of the right leg. When he was admitted to an evacuation hospital the following day the wound was described as located 6 to 8 cm. below the anteromedial lip of the tibia, midway between the tibia and the fibula. The wound of exit, which was small, was located in the calf posteriorly. The leg was warm and of good color but was markedly edematous. Pulsation could not be felt in the dorsalis pedis.

Exploration was undertaken 1 April, 32 hours after wounding. The missile track passed through the opening above the interosseous membrane in close proximity to the anterior tibial artery. The peroneal nerve was not injured. There was no visible injury to the vessel wall, but the vessel was in complete spasm for a distance of at least 10 cm. distally. Three hours after operation pulsation still could not be felt in the dorsalis pedis artery, but 4 hours later pulsation was easily felt and the volume improved progressively thereafter. Edema also subsided progressively until the patient was evacuated on the fourth post-operative day.

Comment. This case is an illustration of short-lived arterial vasospasm caused by a wound close to the vessel which did not, however, directly involve it. If lumbar sympathetic block had been done promptly after operation, improvement might have occurred even more rapidly.

Case 17. A 26-year-old soldier wounded near Cassino, Italy, incurred shell-fragment wounds of the right leg in the upper third and of the right thigh in the lower third. The wounds were debrided at an evacuation hospital 15 hours later. A shell fragment was removed from the right leg through an elective incision along the head of the fibula. Exploration of the posterior tibial artery showed it to be in complete spasm but pulsations were felt in the popliteal artery. The dorsalis pedis pulse could not be felt and the foot was cold. Lumbar sympathetic block was done promptly after operation and was repeated three times in the next several days. The results were not recorded.

When the patient was admitted to a general hospital 13 days after wounding, the right foot was slightly swollen and was colder than the left. There was some question about whether peripheral pulses were detectable. Two days after admission secondary closure of the wounds was done and paravertebral procaine hydrochloride block was repeated because the foot was cyanotic and clammy. The wounds healed normally but the foot continued as described except immediately after sympathetic block; then it was transiently warm and pink. Eight blocks were carried out over a 14-day period. Femoral pulsations continued to be normal, but the popliteal, dorsalis pedis, and posterior tibial pulses were never palpable. A lumbar ganglionectomy was therefore done on the 30th day after wounding. Eight hours later the foot was described as flushed and warm, and all the peripheral pulses became palpable and so remained.

Comment. In contrast to the preceding patient (Case 16) the arterial vasospasm in this patient persisted for an unusually long period of time. The indications for ganglionectomy were sound and its performance clearly contributed to the good results.

Therapy. Treatment in vasospasm is always based upon an attempt to counteract the condition and to produce maximum vasodilatation in the involved extremity. This was the objective in such cases in World War II. A few attempts were made to induce and maintain vasodilatation by the use of such a vasodilating agent as whiskey, but in general, chemical or surgical means were preferred. The logic of these methods is evident: Since the disturbance is apparently the result of a vasomotor reflex initiated in the traumatized tissues, and since vasoconstrictor impulses are transmitted by way of the

sympathetic nerve fibers, interruption of these impulses by the means suggested is the proper mode of treatment.

Interruption of sympathetic impulses, usually by paravertebral injection of 1-percent procaine hydrochloride solution, was widely practiced by American surgeons in World War II, but in the material available for analysis it was possible to determine definitely in only 280 cases that the procedure had or had not been performed. The results (Chart 17) provide no substantial evidence that the method was of any value. The incidence of amputation in the group in which sympathetic block was performed was only slightly less than the incidence for the group as a whole, while the incidence in the cases in which ganglionectomy (which was preferred to repeated nerve blocks) was performed was greater than for the entire series.

Familiarity with the clinical material permits a different and more accurate interpretation of results than the figures on sympathectomy might suggest. Actually, sympathectomy was used only as a last resort when it had already become apparent that the limb would not survive. Sympathetic block was

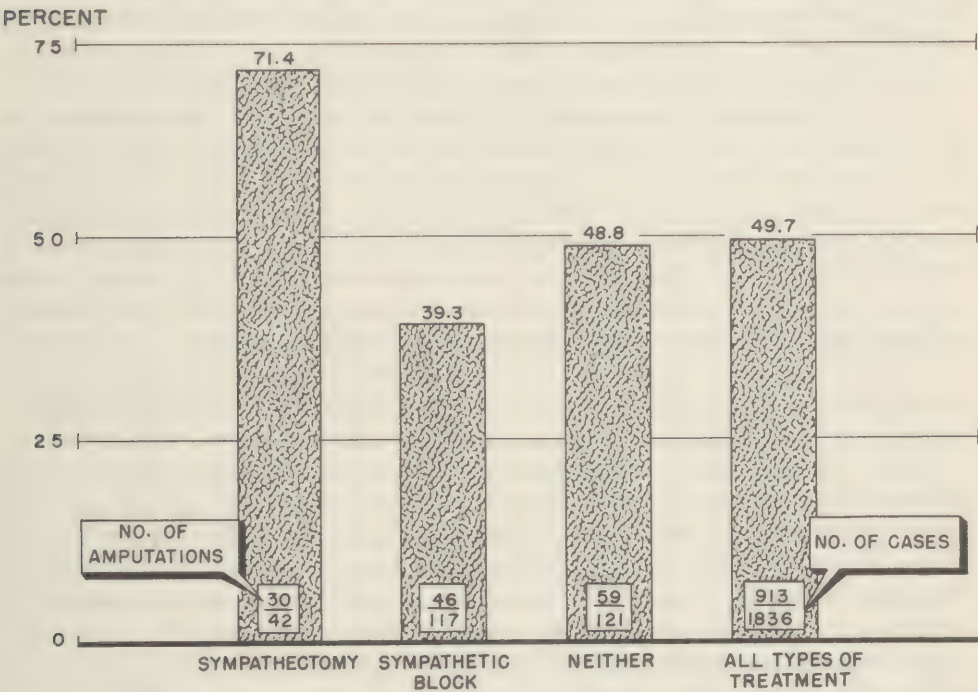


Chart 17. Results of sympathectomy and sympathetic block in comparable arterial wounds in American battle casualties in World War II. The data depicted are based on a selected group for which the necessary information was available. They do not include all arterial wounds during World War II. Only those cases where, for the same artery, there were examples of management with sympathectomy and sympathetic block, and also examples where neither had been used, are included in this chart.

more frequently instituted as part of the immediate postoperative routine and was continued until the outcome in respect to survival or death of the limb became obvious.

When these facts are known, the apparently poor results of sympathectomy and the apparently better results of sympathetic block are more readily understood.

It should also be emphasized that it is extremely difficult to evaluate such procedures as these on a purely statistical basis. First, it was not always possible to determine from the records that the block had been performed effectively. Second, proper objective methods to determine the efficacy of the procedure are lacking, and suitable controls upon which to base an evaluation of results are also lacking. Survival or death of the limb is not a critically objective test; the outcome does not permit a clear decision whether the therapeutic measures employed in a given case have influenced the results and it can serve as a criterion only when sufficiently large numbers of cases are available for statistical evaluation. Third, and perhaps most important of all, the ultimate viability or death of the part was established in most cases at the time of wounding, and the margin within which improvement could be demonstrated was therefore so small that great numbers of cases would be required to establish the efficacy of any single procedure on a statistical basis.

Despite the lack of statistical proof, there is much clinical evidence in favor of sympathectomy and sympathetic block. The personal testimony of numbers of surgeons indicates the usefulness of these procedures. In case after case moderate degrees of tense swelling and muscle pain characteristic of ischemia were observed to regress and the temperature of the limb was observed to rise following their use. Most American surgeons who worked in forward areas regarded interruption of the sympathetic system when practicable as perhaps the most useful adjunct method of treatment available to them.

Cohen¹³⁵ was among the few experienced observers unwilling to accept the theory that arterial spasm is influenced by local or distant autonomic reflexes, his position being that it is myogenic in origin. He also cited evidence to indicate that blockage of the vasomotor control of a wounded limb was dangerous because vasodilatation of the skin was not accompanied by vasodilatation in the muscles, and harm was done by diverting blood from the muscles into the skin. For this reason he deprecated the use of sympathetic block or sympathectomy as a therapeutic measure to combat traumatic vasospasm associated with direct injury. His reasoning, however, seems inconsistent since he was willing to use sympathectomy to control vasospasm associated with a crushing injury or following the prolonged application of a tourniquet, on the ground that the vasospasm observed under these circumstances is of a reflex nature. It seems highly unreasonable to assume that vasospasm can be initiated reflexly by one type of trauma and not by another, especially since the end results of both

¹³⁵ See footnote 48, p. 98.

varieties take the form of ischemia from tissue damage. It seems equally unreasonable to assume that sympathetic block or sympathectomy can be injurious in one of the varieties of vasospasm and beneficial in the other.

Aneurysms and Arteriovenous Fistulas

As has been pointed out, the nature of the missiles employed in World War II altered in many respects the character of the wounds produced by them. This was particularly true of vascular injuries. In addition to wounds caused by machinegun and rifle bullets and high explosive shells, multiple injuries were frequently caused by fragmentation of land mines and grenades. It was not uncommon to find as many as a hundred small, separate wounds scattered over the surface of the body, none of them serious enough to cause death but many of them capable of producing aneurysms. The incidence of aneurysms and of multiple aneurysms was therefore greater in World War II than it had been in any previous war. The same was true of the incidence of arteriovenous fistulas.

Since, as will be pointed out shortly, the policy of management of aneurysms and arteriovenous fistulas was entirely conservative, the majority of patients with these conditions received their definitive treatment in Zone of Interior vascular centers. (See Chapter IV.) As a matter of fact, when these complications were seen overseas it was almost without exception in hospital installations of the base sector. They usually took weeks to become manifest and would scarcely have had time to develop in field and evacuation hospitals of corps and army areas. The diagnosis was probably missed in some cases overseas, but in many others the lesions still had not developed when the patients were evacuated. Not uncommonly their presence was first detected by the patients themselves who days or weeks after the injury noticed a "buzzing" in the region of the wound. Traumatic aneurysms and arteriovenous fistulas were practically always observed in injuries which caused only partial interruption of the flow of blood through the vessel.

The plan of management of arterial aneurysms and arteriovenous fistulas was basically conservative for several reasons: (1) Delay permitted whatever infection might be present from the original wound to subside completely. (2) Delay lessened the chances of secondary infection when operation was done. (3) Delay diminished the chances of secondary hemorrhage which was a possibility in any case in which there was extravasation of blood into the tissues. (4) Delay provided for the occasional case in which a traumatic aneurysm might heal spontaneously. (5) Delay allowed time for an adequate collateral circulation to develop.

Of all the reasons listed in favor of conservative treatment of aneurysms and arteriovenous fistulas the last-named was the most valid. Major vessels could not be ligated and divided with safety until such a circulation had developed. In the natural course of events when the blood flow through the main artery of a limb was impeded or partially diverted by trauma, a collateral cir-

ulation developed and took over the function of supplying the limb with blood. This development, however, was a matter of weeks, not of days. It was thought to reach its maximum not less than 10 weeks, and more often not less than 12 to 16 weeks, after the need for it first arose. It was therefore the established policy in all theaters of operations that in the absence of indications to the contrary, surgery for traumatic aneurysms and arteriovenous fistulas should be deferred for 3 to 4 months after injury and should be carried out preferably in a vascular center in the Zone of Interior.

In a certain number of cases, operation for arterial aneurysms and arteriovenous fistulas had to be undertaken in overseas theaters because the circumstances did not permit delay. Surgery was then more or less an emergency matter. The chief indications were impending rupture, hemorrhage, infection, threatened gangrene of the extremity because of circulatory deficiency, increase in the size of the mass, signs of pressure on neighboring vessels and nerves, severe pain, and evidences of strain on the cardiovascular system. These indications were more likely to appear in pulsating hematomas (false aneurysms) than in true aneurysms and arteriovenous fistulas. As the following cases show, more than one indication was frequently present in a single case.

Case 18. A 22-year-old soldier was wounded accidentally in Italy by a bullet from a .45 caliber pistol 20 September 1943. The bullet entered just beneath the middle third of the left clavicle and emerged from the thorax through the left scapula. The subclavian artery was damaged. The wounds of entrance and exit were debrided in an evacuation hospital about 3½ hours after injury. It was noted that the pulse was less strong in the left wrist than in the right, which suggested that the subclavian artery was in spasm. Roentgenograms revealed fragmentation of the scapula but no injuries of the thorax.

The day after operation examination showed paralysis of the left arm, forearm, and hand except for slight deltoid, triceps, and supinator action. Sensation was present in the axillary area and in the area supplied by the medial and dorsal antebrachial cutaneous nerves. It was concluded that the injury involved the inner cord of the brachial plexus completely and at least half of the posterior cord below the level of the axillary nerve.

On 23 September, when the patient was examined at a general hospital to which he had been evacuated by air, the left arm was found flushed and slightly edematous throughout its length. By 26 September the edema had subsided to a considerable degree but the radial pulse remained weaker in the left arm than in the right. On 28 September, when he sat up for breakfast, about an ounce of blood oozed through the dressing over the left clavicular region. Examination showed edema of the entire left arm with distention of the veins. The palm of the left hand was moist but no voluntary motor activity could be elicited. Operation was undertaken 48 hours later because of the complaint of pain and the continuing evidence of compression of the brachial plexus by the aneurysm. The aneurysm arose from the first portion of the axillary artery. After a rather difficult operation the subclavian and axillary arteries were ligated in continuity proximal to the origin of the subscapular artery. A transfusion of 1,000 cc. of whole blood was given during the procedure.

At the end of the operation the hand was warm and of good color. Recovery was uncomplicated and the patient was in good condition when he was evacuated farther to the rear 26 October.

Case 19. A 23-year-old soldier was wounded in action by enemy shell fragments on the Anzio beachhead 20 February 1944. He incurred multiple wounds of the left buttock, the left thigh and leg posteriorly, and the left popliteal area. There were no fractures. He was given first aid, including a unit of plasma, within 3½ hours after wounding and was admitted

to an evacuation hospital shortly afterward where all his wounds were debrided. Roentgenograms showed foreign bodies beneath the base of the left fifth metatarsal and in the left thigh medially and also medial to the lesser trochanter.

When the patient was received at a general hospital in the base 23 February after evacuation by hospital ship, examination showed impending gangrene in the toes of the left foot which was slightly edematous. He complained of pain in the foot which he said was "worse" at night. The calf was swollen and tense. The skin over the lateral aspect of the leg was hot and reddened. No pulsations were felt in the popliteal space or below it. The site of the arterial lesion responsible for the vascular insufficiency was not determined. After two lumbar sympathetic blocks with procaine hydrochloride, pain lessened and swelling decreased in both the leg and the foot.

On 25 February edema of the extremity was more prominent. The first four left lumbar sympathetic ganglia were blocked with procaine hydrochloride. On 27 February the toes were dark, the calf was tense, and the foot was edematous. The patient was able to move the ankle and toes. By 1 March the foot was still swollen and there was definite gangrene of the great toe and the fourth and fifth toes. The following day the erythrocytes numbered 2,570,000 and the leukocytes 11,900 per cubic millimeter. By 4 March all of the toes of the left foot were undergoing the changes of dry gangrene and there was gross discoloration of the skin of the distal half of the foot. On 5 March the erythrocytes numbered 3,410,000 and the leukocytes 12,500 per cubic millimeter; gangrenous changes (dry) continued to progress slowly proximally on the foot. Pain was limited to the foot.

On 14 March the patient himself noted a peculiar sensation in the thigh near the left inguinal region. Examination showed the characteristic "machinery" murmur of an arteriovenous fistula. The blood pressure in the arm was essentially unchanged when the aneurysm was occluded. On 17 March an electrocardiogram was reported as being normal. The pulse rate was 120 beats per minute before the arteriovenous fistula was occluded by pressure and 96 and 100 beats per minute while it was occluded. A firm, diffuse, tense swelling appeared in the peroneal group of muscles and was progressive.

By 30 March the dry gangrene in the foot was well demarcated. On the sole it extended almost to the heel. On 1 April left lumbar sympathectomy was performed with the aid of spinal analgesia. By 6 April there was noticeable improvement in the circulation of the left leg and the tense swelling of the peroneal group of muscles had somewhat receded.

On 8 April the arteriovenous fistula, which was located about 5 cm. below Poupart's ligament, was excised. Thereafter there was continued improvement in the circulation. Before the patient was evacuated to the Zone of Interior in May (the exact date is not known) a guillotine amputation was done just above the ankle.

Comment. The cause of the early vascular insufficiency in this case is not clear. It may have been caused by arterial spasm, or it may have been the result of a small arteriovenous fistula. The outcome might have been different if it had been recognized earlier and if the circulation had been aided promptly by sympathetic block or sympathectomy. When the aneurysm was clearly established, 3 weeks after wounding, the pathologic changes in the leg had become progressive. The course in this case seemed to furnish an indication for excision of the aneurysm rather than for temporizing measures.

Case 20. This 25-year-old soldier was wounded by shell fragments in Italy 7 December 1943. He incurred multiple wounds of the abdomen, chest, and extremities. The following day in a field hospital all wounds were debrided, a colostomy was established because the colon was the site of several injuries, and "a diffuse axillary hematoma was drained through a stab wound in the axilla." This hematoma was related to an anterior wound of the right shoulder.

When the patient was evacuated to a general hospital 16 days after wounding, a mass was palpable on the right side in the subpectoral region. Three days later the mass suddenly increased in size and the patient complained of severe, burning pain which involved the right upper extremity. Examination showed the mass to be expansile. A systolic bruit was heard over it. The right arm was weak and there was hypesthesia over the radial and median nerve distribution. The blood pressure was 104 mm. of mercury systolic and 26 diastolic on the right side, and 130 mm. of mercury systolic and 78 diastolic on the left.

Because of the increase in the size of the mass and the pain, which was difficult to control even with morphine, operation was carried out 31 December. The first portion of the axillary artery was exposed by division of the clavicle and was controlled by means of rubber tubing passed under it. The aneurysm was then approached through a separate incision. It was opened and cleared of blood clot. The arterial wound was at the level of the anterior circumflex humeral branch which was ligated. The axillary artery was then ligated and divided across the wounded area. The lesion was thought to be proximal to the subscapularis artery. The missile had also lacerated a small trunk of the median fasciculus of the brachial plexus as it lay anterior to the axillary artery. The circulation appeared satisfactory at the conclusion of the operation, in the course of which the patient received 1,500 cc. of whole blood.

The day after operation the function of the right hand was better than it had been before operation. The right hand was cooler than the left. The radial and ulnar pulses were not palpable but there was good capillary circulation. The sympathetic nerve supply of the right arm was blocked twice with procaine hydrochloride.

When the patient was evacuated 46 days after operation he was showing satisfactory progress. The function in the right hand had improved progressively though there was still no radial pulse.

It was usually a simple matter to determine the status of the circulation in the limb. When interruption of the blood flow was only partial, the limb was cool but not cold. The muscles distal to the wound were essentially normal and were not tense or swollen. Oscillations were detectable with a standard oscillometer or with a sphygmomanometer. Vascular spasm was likely to be present in these cases and to respond well to repeated sympathetic block with 1-percent procaine hydrochloride. When emergency operation was necessary sympathectomy was frequently performed either before or after operation to assure maximum vasodilatation and thus increase of circulation in the involved part. The results of surgery for arterial aneurysms and arteriovenous fistulas, whether the operation was done overseas or in the Zone of Interior, were generally excellent.

Other Complications

Volkman's Ischemic Contracture. In many cases of vascular injury a curious phenomenon became evident after interruption of the blood supply, sometimes as soon as 12 hours afterward, in the form of a tense, hard swelling of the muscles (Fig. 8). It was particularly likely to occur after wounds of the popliteal artery, but also occurred after wounds of the brachial and femoral arteries. When the femoral artery was injured the swelling was likely to be limited to groups of muscles in the leg, such as those in the anterior tibial compartment. The involved extremity became progressively larger, the maximum size being reached in 36 to 48 hours. It was characteristically hard and tense



Figure 8. Tense swelling of muscles of calf, without significant subcutaneous edema, 12 hours after transection of popliteal artery. Fasciotomy, useful in some cases of this kind, was not successful in wounds involving the popliteal artery in this experience.

on palpation. Subcutaneous edema eventually appeared, but was often absent at first and might not appear until 3 to 5 days after injury.

The nature of this brawny swelling in an ischemic extremity was never entirely clarified. An occasional biopsy specimen showed no evidence of extracellular edema or infection. The swelling was sometimes compared to the changes observed in rigor mortis, but the comparison was actually not valid since in ischemic swelling the muscles always appeared to be contained under considerable pressure by the enveloping fascia. It was sometimes explained as the result of generalized intracellular edema of the ischemic muscle cells, while the subcutaneous edema which appeared later was explained as the result of venous stasis and of inflammatory changes in the leg. More probably the chain of events was as follows: When the main arterial supply to the muscles of the affected extremity was suddenly interrupted, a vicious circle promptly developed in which impairment of the capillary circulation was increased by swelling of the muscular tissue and the pressure of the enveloping fascia. The swelling and pressure, in turn, were increased with increasing impairment of the capillary circulation until a stage was eventually reached at which the circulation ceased entirely.

On the basis of these assumptions, fasciotomy¹³⁶ was recommended in these cases, both for those in which the condition seemed incipient and progression likely and for those in which the patient was not seen until it had become fully developed. Longitudinal incisions were used for both upper and lower extremities. In the leg the incision was made posteromedially to decompress the muscles of the gastrocnemius-soleus group, and anterolaterally to decompress the anterior tibial compartment. In the forearm the incision was made on the volar aspect. When the fascia was incised, it spread widely and the pale underlying muscles bulged forcibly through the incision.

Fasciotomy was open to the criticism that the incision might destroy the collateral circulation from the skin and thus further compromise the regional circulation by introducing the risk of infection. On more theoretical grounds, however, these objections were superseded by the consideration that the operation might permit the reestablishment of circulation through the ischemic musculature. Certain British surgeons¹³⁷ in the Mediterranean theater were enthusiastic advocates of fasciotomy and reported excellent results with it. American surgeons in the area were much less favorably impressed by its possibilities. In the limited number of cases in which it is known to have been used, results were occasionally good (Cases 10, 21) but they were uniformly poor in wounds of the popliteal artery (Case 11).

Case 21. A 25-year-old soldier incurred an accidental wound of the right arm 21 November when two carbine bullets perforated the arm through the biceps and lodged in the cervical region and the superior mediastinum. The brachial artery and vein were severed and the median nerve was partially severed and badly traumatized. There were no fractures. A tourniquet was applied to the right upper arm 5 minutes after wounding and was released and reapplied in about an hour.

When the patient was admitted to a station hospital 1 hour and 45 minutes after the accident there was a large, tense hematoma in the right arm extending into the axilla. The arm was cold and limp and was without sensation. There was no sensation in the forearm; its muscles were soft and relaxed. Radial and ulnar pulses were absent.

Operation was performed at once with the patient under thiopental sodium anesthesia. The incision was made over the medial edge of the biceps muscle. Clotted blood was evacuated. The brachial artery and vein were ligated above the profunda branch. The ulnar nerve was not identified.

Ice bags were applied to the arm and forearm as soon as the operation was concluded. About 11 hours later swelling and stony hardness were observed in the uninjured forearm, and it was also noted that the superficial veins were dilated. No pulses were palpable at the wrist. The wrist and fingers were held stiff in flexion. When the ice bags were discontinued 12 hours after operation the patient said that the arm had been more comfortable when they were in place. No other effects were noted from their use.

Twenty-four hours after the first operation (about 26½ hours after wounding), with the patient under thiopental sodium anesthesia, the forearm was decompressed by 3 incisions, 1 dorsal and 2 ventral, which were carried throughout the length of the arm and through the deep fascia. The surgeon described the tissues as "wet." Shortly after the

¹³⁶ See footnotes 22, p. 70 and 126 (1), p. 127.

¹³⁷ (1) Clark, R.: Forward surgery of injuries to major blood vessels. *Proc. Cong. C. M. F. Army Surgeons, Rome, 12-19 Feb 45*, p. 107-111.

(2) See also footnote 42 (1), p. 95.

operation had been completed, the wrist and fingers which had been held in flexion could be extended passively. The forearm and hand were put up in a plaster splint with the hand in the position of function.

Recovery was uneventful. On 28 November, although the pulses were still not palpable at the wrist, the fingers were warm. By 9 December the swelling of the forearm was less, but the tissues were still not soft to palpation. There was beginning ability to extend the wrist and some return of sensation in the radial nerve distribution on the hand, but the median and ulnar nerves showed no return of motor or sensory power. The patient was not observed after this date.

Comment. It is doubtful that the brief refrigeration served any useful purpose in this case. On the other hand, there seems little doubt that the arm would have been lost if fasciotomy had not been performed promptly.

The condition just described may be classified as an early phase of the type of contracture known in civilian practice as Volkmann's ischemic contracture and usually observed in injuries associated with fractures. Contractures involving the forearm and hand, and less frequently the leg and foot, constituted one of the most crippling sequels of acute ischemia consequent upon arterial wounds. They apparently developed as a result of severe ischemia which stopped just short of causing actual gangrene. The incidence of this complication in World War II is not known, but it was apparently relatively infrequent. In 1 series of 35 arterial injuries observed at a vascular center in the Zone of Interior there were 4 instances of contractures, and in another series of 77 injuries there were 20 instances. These figures are, of course, weighted: Patients who were hospitalized in vascular centers were sent there because of complications.

The management of these contractures was not very satisfactory. In spite of every effort to improve the circulation, including sympathectomy, the results were only moderately good at best. Other attacks upon the problem took the direction of orthopedic plastic operations and physiotherapeutic measures designed to make the best use of whatever functioning muscle tissue might remain.

Causalgia. Causalgia was not a frequent complication of the vascular injuries observed in World War II. If only the figures from vascular centers are considered this observation might seem to be incorrect; there were 17 instances in a series of 77 cases observed at a vascular center. As just pointed out these figures are weighted in that they include only patients in whom complications required their reference to the vascular centers. In a series of 75 cases of causalgia reported by Ulmer and Mayfield,¹³⁸ the etiologic factor in no instance was an arterial injury. In the cases observed at the vascular centers the incidence of causalgia was always higher when nerve injuries were associated with the vascular injuries.

The great majority of patients with causalgia responded well to sympathetic block and sympathectomy.

¹³⁸ Ulmer, J. L., and Mayfield, F. H.: Causalgia; study of 75 cases. *Proc. Neuropsychiat. Conf., Sixth Serv. Command*, 179-184, Jul 1945.

Circulatory Insufficiency. Clinical evidences of circulatory insufficiency were seldom apparent soon after wounding in the army areas or even in the communications zone. They became manifest when the wounded became ambulatory and were rehabilitated for either return to duty or discharge from the Service. Since a detailed discussion is given in Chapter XV, only brief mention is necessary here. Clinical manifestations included color changes, intermittent claudication, and, in the more severe cases, partial paralysis. Some patients experienced only mild discomfort even after exertion, while others had pain even when resting. Similar observations had been made during World War I and have been described by numerous observers in civilian practice.¹³⁹

No accurate data are available concerning the exact incidence of this clinical manifestation of acute arterial injuries in World War II. In one sample of 88 cases, however, vascular insufficiency severe enough to be manifested clinically was observed in 68 percent. Two patients had had early sympathectomy and in 49 the operation was done late. With the exception of 1 patient, all were definitely improved.

The concept of sympathectomy in the management of these cases was developed by Leriche¹⁴⁰ in World War I and this procedure apparently provided the best results reported in the management of this condition in World War II, though it was, of course, not always successful.

Case 22. This 23-year-old private in the Infantry was accidentally shot by another soldier 15 May 1944 on the Anzio beachhead. The wound was debrided at a field hospital 4½ hours after wounding. The left femoral artery and vein were ligated in the midhigh distal to the profunda femoris branch. Sulfadiazine therapy was instituted and lumbar sympathetic procaine hydrochloride injections were done daily for 3 days. On 23 May the wounds were closed and healing progressed satisfactorily.

When the patient was evacuated to a general hospital 26 May, examination revealed the left foot to be colder than the right. No pulsations could be felt in it. The foot was not swollen and the color was good. Both feet were sweaty. Two days later a transfusion of 1,000 cc. of whole blood was given.

On 20 June, which was a cold day, both feet were cold and moist. The left foot was slightly cyanotic and no pulses were demonstrable. On 8 July the posterior tibial pulse could be felt without difficulty. The dorsalis pedis pulse was weak. The temperature of both feet was about the same; both were cold and sweaty. The patient could walk about 400 yards slowly and without pain, but climbing two flights of stairs at moderate speed caused pain in the left calf. On 31 July (a cool day) the left foot was cooler than the right;

¹³⁹ (1) Burrows, H.: Paralysis following arterial injuries. *Brit. M. J.* 1: 199-203, 16 Feb 18.

(2) Leriche, R.: De la sympathectomie péri-artérielle et de ses résultats. *Presse méd Paris* 25: 513-515, Sep 1917.

(3) Leriche, René: *La Chirurgie de la Douleur*. Paris, Masson et Cie, 1940.

(4) Leriche, René: *Physiologie Pathologique et Chirurgie des artères*. Principes et méthodes de la Chirurgie Artérielle. Paris, Masson et Cie, 1943.

(5) Leriche, R., and Heitz, J.: Résultats de la sympathectomie péri-artérielle dans la traitement des troubles nerveux post-traumatiques d'ordre réflexe (type Babinski-Froment). *Lyon Chirurg.* 14: 754-792, Jul-Aug 1917.

(6) Leriche, R., and Werquin, M. G.: Effects of arterial ligation on the vasomotor system. *Lancet* 2: 296-297, 7 Sep 40.

(7) Mitchiner, P. H.: Injuries of blood vessels and their treatment. *St. Thomas's Hosp. Gaz.* 38: 92-96, Jul 1940.

(8) Mitchiner, P. H.: Treatment of wounds of blood vessels. *Post-Grad. M. J.* 16: 157-161, May 1940.

(9) See also footnotes 12, p. 64; 38, p. 84; 103 (5), p. 115; 113 (2), and (3), p. 116.

¹⁴⁰ See footnotes 139 (2) and (5).

both were sweaty. At this time, 2½ months after injury, the patient could walk only 200 to 300 yards at moderate speed without complaining of pain in the left calf.

On 10 August left lumbar sympathectomy was performed, with the aid of spinal analgesia, through an anterior muscle-splitting extra peritoneal approach. The second and third lumbar ganglia and the connecting sympathetic trunk were excised. By 26 August, 16 days after operation, the patient could walk at least 10 times the distance he could walk prior to sympathectomy at the same rate of speed without cramping the calf. On 20 September, 41 days after sympathectomy, he walked 1¼ miles without pain. The foot and leg were warm and dry, and the left foot was now warmer than the right. It was not swollen. The posterior tibial pulse was fairly strong.

As of this date the patient returned to limited duty in the Mediterranean theater.

Case 23. This 28-year-old Infantry sergeant was wounded in action in Southern France 19 August. He received penetrating wounds of the left hip and thigh and right heel, and lacerations of the right femoral artery and vein. The wounds were debrided at a field hospital (apparently soon after wounding, though the exact hour is not available) and the femoral vessels were ligated at the site of injury below the profunda femoris branch.

Penicillin therapy was begun immediately after operation and lumbar sympathetic injection of procaine hydrochloride was done daily for 3 days. When the patient was evacuated to a general hospital in Italy 25 August, he was quite pale. The plasma protein concentration was 6.7 gm. per 100 cc., the hemoglobin 8.2 gm. per 100 cc., and the hematocrit value was 24.1 percent. The right foot was pale, slightly cyanotic, and cooler than the left foot, but was not swollen. No pulses could be felt in it.

The patient was given 1,000 cc. of whole blood 26 August. When he had received about 100 cc. of a second transfusion the following day he had a severe reaction with back pain, numbness, tingling of the extremities, dyspnea, and cyanosis. The symptoms were promptly relieved with adrenalin. When the blood was rechecked it was found compatible and the reason for the reaction could not be determined.

Secondary closure of the wounds was done 27 August. A transfusion of 1,000 cc. of whole blood was given during the operation. Healing was satisfactory.

On 2 October, 2 months after injury, the patient complained of cramping pain in the right calf after walking 500 to 600 yards at moderate speed. The pulses were now palpable, although weak. The foot was cold and pale on cold days. On 28 October right lumbar sympathectomy was done, with the aid of spinal analgesia, through an extraperitoneal muscle-splitting anterior abdominal incision. The second and third lumbar ganglia and the connecting trunk were excised. Soon after operation the right foot was found to be dry and to be warmer than the left foot. By 6 November the pulses in the foot were of fairly good volume. A week later the patient was able to take daily walks without cramping in the calf. By 25 November, 3 months after injury and 1 month after sympathectomy, he could walk 2 miles at moderate speed without pain in the calf. The right foot was dry, not edematous, and warmer than the left. The color was good and the pulses of good volume.

Soon afterward the patient was returned to limited duty in the Mediterranean theater.

Case 24. A 22-year-old soldier was accidentally wounded when one of his own chemical mortar shells exploded prematurely in Italy 23 November. The shell fragment caused a complete interruption of the right femoral artery and vein. There were no fractures. A tourniquet was applied promptly above the wound and firm dressings were used. He was admitted to a field hospital platoon 2 hours after injury. Resuscitation was accomplished with 5 units of plasma (in addition to a unit of plasma previously given in the first aid station) and 1,000 cc. of whole blood.

Operation was performed with the patient under ether anesthesia 5½ hours after injury. The foreign body was removed and the severed femoral artery and vein were ligated. A right lumbar ganglionectomy was then done with removal of the second, third, and fourth

lumbar ganglia. Four units of plasma and 1,000 cc. of whole blood were given during operation and gas gangrene antitoxin was given immediately afterward. A well-padded circular cast was applied and bivalved.

On 24 December, the day after operation, the right leg was warm to 8 inches below the knee. The remainder of the leg and the foot were cool. On 27 December the circulation in the right leg was good and it was warm down to the junction of the middle and lower thirds. Below this level the leg was cyanotic and cold (Fig. 9). It was thought that demarcation would take place low enough to save the knee.

No particular change was noted in the extremity until 2 January. The muscles continued to be tense and on this date pitting edema was first observed. The following day, although there were no systemic signs or symptoms, supracondylar amputation of the leg was decided on because of the absence of apparent improvement in the foot and leg. Amputation was done above the knee because of poor circulation in the muscle of the leg.



Figure 9. (Case 24.) Complete severance of right femoral artery and vein treated by ligation below profunda femoris. Dry gangrene of tips of great toe and second toe 4 days after operation with line of demarcation at junction of middle and lower third of leg. Supracondylar amputation was required in this case because of muscular ischemia.

Comment. This is a case in which sympathectomy failed to achieve the desired results. It also illustrates the possible discrepancy between the appearance of the skin and the condition of the underlying muscles. The appearance of the skin, and the apparently excellent circulation and healthy subcutaneous tissues, suggested that the muscles would be in equally good condition. Actually, although the skin was viable, the muscles, as frequently happens in this type of case, were found to be necrotic. In retrospect, it would have been wiser to delay amputation as long as there was no evidence of toxicity from the ischemic leg in the hope of saving the stump below the knee.

CHAPTER IV

Arterial Aneurysms and Arteriovenous Fistulas

General Considerations

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For descriptive purposes, battle-incurred vascular injuries may be divided into:

1. Wounds in which the blood vessel is completely severed or in which vasospasm exists to such an extent as to render the blood supply so impoverished that death of the part or useless fibrotic tissue results.
2. Wounds in which the damaged vessel is only partially severed, producing a false aneurysm or arteriovenous fistula.
3. Wounds which result in activation of previously existing blood vessel disorders, including vascular tumors.

In numerous instances of complete vascular severance, death inevitably occurred promptly on the battlefield because of excessive loss of blood. In patients who survived, ligation of the vessel above the point of injury was often the only feasible procedure. Early repair of the vessel while theoretically possible and always desirable was not usually practicable under existing conditions. Sometimes, particularly when small arteries were injured, clot-formation and retraction of the severed ends occurred, the process probably being facilitated by the lowered vascular tension associated with wounding. Late complications were not usual in this type of vascular injury. They were also the exception in injuries superimposed on preexisting cardiovascular or peripheral vascular disease, very few of which were observed because physical examination at induction centers was sufficiently thorough to prevent the induction of individuals with such conditions. The situation was quite different, however, when vascular injury resulted in incomplete severance of the affected vessel. Late complications were then relatively frequent.

The number of aneurysms and arteriovenous fistulas of traumatic origin observed in vascular centers in the Zone of Interior in World War II far exceeded any similar series ever recorded. This increase may be attributed to the introduction of higher velocity projectiles. In addition to the ordinary

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wounds caused by machineguns, rifle bullets, and shell fragments, a great many multiple injuries were produced by fragmentation of land mines, grenades, and aerial bombs. These last-named produced a great many small individual wounds—thus increasing the incidence of trauma to the blood vessels.

Numerous additional factors figured in the development of arterial aneurysms and arteriovenous fistulas after vascular injuries in World War II. The majority of these would likewise be operative in noncombat-incurred injuries. They included (1) the particular artery involved; (2) the size and other characteristics of the injury to the vascular wall; (3) the size and direction of the channel which served as an exit for the hemorrhage, that is, the path of the missile; (4) the nature of the surrounding tissue, which determined the possibilities of controlling hemorrhage; (5) the level of arterial tension; (6) the degree of pressure applied to control hemorrhage; (7) the adequacy of splinting; (8) the method of transportation; and (9) the speed with which definitive treatment was supplied.

The wide variety of possible causes of vascular injuries, combined with the inconspicuousness of many combat-incurred wounds caused by minute fragments of exploding missiles, made it inevitable that in the press of evacuating large numbers of casualties in theaters of operations some vascular injuries were initially overlooked, and the subsequent discovery of arterial aneurysms and arteriovenous fistulas entirely unexpected. Openings in blood vessels produced by small missiles frequently caused no early symptoms and it was natural that these should be overlooked, or their significance not appreciated. This was particularly true if more extensive injuries distracted the surgeon's attention from them. It was also understandable that under combat conditions an incomplete, or even an incorrect, diagnosis might be carried by a wounded soldier for a considerable period of time.

One reason that these lesions were often overlooked was failure to bear in mind the fact that blood vessels are usually accompanied by nerves. The manifestations of nerve injuries were frequently so striking that they overshadowed other damage in the same area.

During World War II it was repeatedly demonstrated that arterial aneurysms and arteriovenous fistulas could easily be missed unless every wound was examined from the standpoint of possible vascular injury, and unless auscultation was part of the routine examination. Furthermore, arteriovenous fistulas present from the onset of injury could be overlooked unless examination was repeated after edema had subsided and hemorrhage into the tissues absorbed.

PATHOGENESIS OF ARTERIAL ANEURYSMS AND ARTERIOVENOUS FISTULAS

To understand the development of traumatic arterial aneurysms and arteriovenous fistulas it is necessary to discuss what may occur as a result of a penetrating wound of the blood vessels.

When an artery is completely severed both ends retract. Hemorrhage may be severe at first but will stop either spontaneously or with the application of pressure, although the artery may require ligation or some attempt at repair. When the vessel is only partially severed an entirely different chain of events ensues. The wound tends to enlarge in the long axis of the vessel as the result of retraction, and hemorrhage is likely to be profuse. If the wound in the soft tissues overlying the vessel is of sufficient size, hemorrhage occurs externally and the indications for immediate control are clear. If the wound is small, the imbrication of muscle, fascia, and skin planes can prevent the escape of blood externally. Blood passes out through the rent in the arterial wall into adjacent tissues where its collection is limited in size and determined in contour by the nature of the surrounding structures, the extent of traumatic damage to these, also the size of the injured artery and of the tear in its wall, as well as by such factors as arterial pressure and effectiveness of the clotting mechanism. This results in the formation of a hematoma which is likely to become a false aneurysm.

As the clot becomes organized, it tends, as has just been intimated, to lose the characteristics of a hematoma and assume the characteristics of an arterial aneurysm. A wall composed of fibrous tissue and supported by surrounding structures becomes evident. The flattened innermost layer of fibroblasts may be suggestive of endothelial cells, and roentgenologic examination sometimes reveals deposits of calcium, but the characteristic elements which compose the wall of a true aneurysm formed by dilatation of an arterial wall are always lacking. The laminated clot continues to undergo organization, but the natural tendency toward spontaneous cure is seldom completely attained and, in the absence of surgical correction, rupture and extension are always possibilities.

When an aneurysm results from the sudden giving way of a diseased arterial wall, the sac which forms may immediately become filled with thrombus. Like the thrombus in the sac of a traumatic aneurysm, this thrombus also tends to be compressed against the sac wall, to adhere to it completely or in part, and to become well organized with the passage of time. Frequently aneurysms which develop by the giving way of a diseased arterial wall are not filled with thrombus. This is particularly true when the aneurysm is of the fusiform type.

In instances in which the external wound is small and the vein injured simultaneously with the artery, groundwork is laid for the formation of an arteriovenous fistula, the artery and vein communicating with each other directly or through the medium of a false sac. It was characteristic of arteriovenous fistulas brought about by combat injuries that they resulted from penetration of shell fragments of small size, just as in civilian practice they frequently followed wounds made by knives and ice picks, injuries accidentally produced in the course of phlebotomy, or the application of transfixion sutures or of

pins for skeletal fixation. A direct shunt of blood from artery to vein could result if these vessels were injured laterally by a missile which passed between them or through them. In through-and-through wounds blood could be shunted directly from the artery to the vein only if the lateral wounds became sealed. Arteriovenous fistulas were particularly likely to develop by this mechanism if the affected vessels were enclosed in a common sheath. Femoral and carotid vessels were for this reason particularly frequent sites of arteriovenous communications. Some arteriovenous lesions followed blows with blunt instruments, no external wound being present.

False aneurysms were sometimes found in association with arteriovenous fistulas. They sometimes lay between the vein and artery and sometimes projected from the site of injury of one vessel or the other. From notes made at the time of operation and from examination of the excised specimens, an analysis was made of the presence or absence of aneurysm and the type when present in 195 patients with arteriovenous fistulas observed at the vascular center of Mayo General Hospital. In Figure 10 some of the types of fistulas and associated aneurysms studied have been diagrammatically represented. Of the 195 cases analyzed, 78 (40 percent) had no aneurysm—there was only a direct communication between artery and vein—(Fig. 10A), 117 (60 percent) had 1 or more aneurysms present (Fig. 10B through J).

In 89 of the 117 patients with 1 or more aneurysms, the artery and vein communicated by means of an interposed saccular aneurysm, or 1 to 2 aneurysms arose from the fistula itself. (Fig. 10B through D.) In 13 patients there were 1 or 2 separate arterial aneurysms in addition to a direct fistula; in 10 of these 13 there was a single aneurysm and in 3 a double arterial aneurysm. (Fig. 10E and F.) In 10 patients there was an aneurysm arising from the vein and a direct fistula. (Fig. 10G.) In 1 patient there was an arterial aneurysm and the artery and vein communicated through a second aneurysm (Fig. 10H); in another there was an aneurysm arising from the vein as well as 1 through which the 2 vessels communicated (Fig. 10I); and in 3 there were aneurysms both of the artery and vein (Fig. 10J). The aneurysms varied in size from a mass 1 cm. in diameter to an ovoid mass about 22 cm. long and 15 cm. in diameter.

When developed in these locations true aneurysms differed in two respects from the false which arose independently: (1) a laminated clot was likely to be present in the sac; and (2) they were usually smaller, the tendency toward expansion being controlled by the decompression afforded by the vein.

Early signs of combat-incurred arteriovenous fistula varied and depended upon the location of the lesion and its size. After injury the patient might become aware of the presence of a pulsating mass or discover the thrill characteristic of the condition. On the other hand, he might notice neither mass nor thrill, in which case the fistula could have been overlooked unless a routine search was made because of the existence of circumstances under which it might develop.

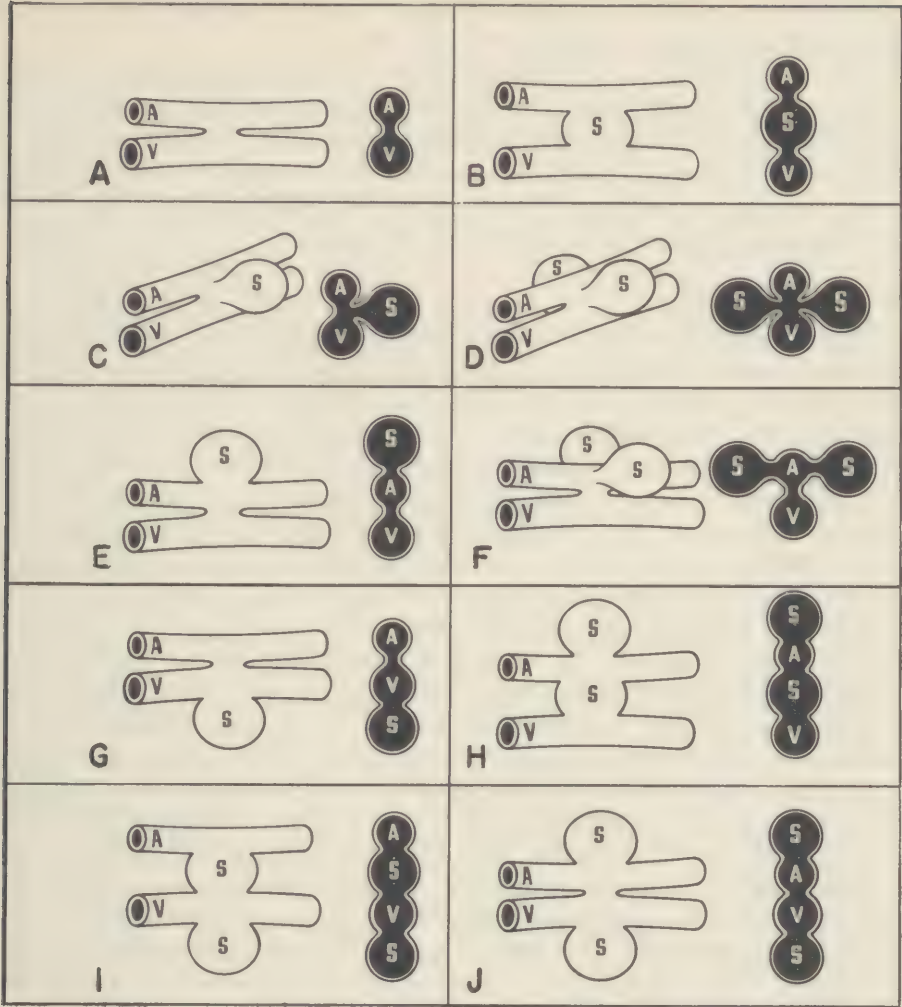


Figure 10. Diagrammatic representation of various types of arteriovenous fistulas and associated aneurysms. Symbols: A, artery; V, vein; S, sac.

Regardless of the site of the fistula, the local clinical evidences of its presence were always the same. The most common sign was a bruit or murmur which could be heard in the region of the lesion. The murmur, in contrast to the murmur of an arterial aneurysm which is purely systolic, was always *continuous* and lasted through both systole and diastole, the systolic accentuation of this sound providing the distinguishing characteristic of fistulas. Although in general, the larger the fistula the louder the murmur, this was not always true; small fistulas sometimes produced loud murmurs. The murmur of a fistula, like a cardiac murmur, might be transmitted for a considerable distance from

the site of origin. Invariably the chief cause of failure to hear the murmur of an arteriovenous fistula was failure to listen for it.

When the murmur was of sufficient intensity, a thrill might be felt. Again, although somewhat indicative of the size of the fistula the intensity of the thrill was not completely reliable evidence of this, since it might be modified by the position of the fistula and by the structures which overlay it. The thrill of an arteriovenous fistula was less well transmitted than the murmur associated with it and was always limited to an area near the lesion.

Differential Diagnosis

Differentiation between a false arterial aneurysm and an arteriovenous fistula was frequently difficult, but was always important since the sequelae, the general and local effects, and the treatment of the two conditions were altogether different. The points of differentiation were the same as those employed in civilian practice: (1) As a rule an arteriovenous communication is characterized by a continuous vibratory thrill and a loud, rough *continuous* murmur with systolic intensification. In a false aneurysm, although a murmur is also present, there is a distinct pause between the systolic and the diastolic phase and the murmur is often heard only in systole. (2) In an arteriovenous communication the murmur is usually transmitted for some distance on either side of the lesion along the course of the vessels, while in a false aneurysm the murmur is only occasionally heard beyond the confines of the dilatation. (3) In an arteriovenous communication, although the presence of a false sac may cause a tumor of considerable size, swelling is not usually pronounced. In a false aneurysm a definite pulsating mass is usually demonstrable. (4) The dilatation of cutaneous veins in the region of an arteriovenous fistula, and the slowing of the pulse on temporary occlusion of the lesion are additional points of differentiation since neither of these signs is associated with the presence of a false arterial aneurysm. (5) While coincident cardiac disease may, of course, be present, the heart is not affected by the presence of an arterial aneurysm. In large arteriovenous fistulas, on the other hand, and in those which persist over a period of time, cardiac dilatation with subsequent cardiac failure is likely to develop.

INCIDENCE

The staffs of the three vascular centers established in the Zone of Interior by The Surgeon General cared for and studied large numbers of soldiers with traumatic arterial aneurysms and arteriovenous fistulas. Two hundred twenty-one arterial aneurysms and 593 arteriovenous fistulas were treated in these centers during World War II (Table 6), but it must not be assumed that these figures represent the total number of such lesions which occurred in patients in the United States or in patients evacuated from overseas theaters to the United States during the course of the war.

TABLE 6. DISTRIBUTION OF 814 ARTERIAL ANEURYSMS AND ARTERIOVENOUS FISTULAS

Location	Arterial aneurysms		Arteriovenous fistulas		Total cases	
	Number	Percent	Number	Percent	Number	Percent
Upper extremity:						
Axillary.....	36	16.3	33	5.6	69	8.4
Brachial.....	54	24.4	30	5.1	84	10.3
Cervical, transverse.....			2	0.3	2	0.3
Humeral, posterior circumflex.....			1	0.2	1	0.1
Interosseous, common.....			1	0.2	1	0.1
Radial.....	12	5.4	2	0.3	14	1.8
Scapular, transverse.....			2	0.3	2	0.3
Subclavian.....	15	6.8	19	3.2	34	4.1
Ulnar.....	7	3.2	9	1.5	16	2.0
Total.....	124	56.1	99	16.7	223	27.4
Lower extremity:						
Calf, to muscles of.....			4	0.7	4	0.5
Circumflex, lateral.....			1	0.2	1	0.1
Femoral.....	18	8.1	144	24.3	162	19.9
Gastrocnemius, muscle branch.....	1	0.5			1	0.1
Geniculate.....			5	0.8	5	0.6
Gluteal, inferior.....			1	0.2	1	0.1
superior.....			3	0.5	3	0.4
Peroneal.....	2	0.9	25	4.2	27	3.3
Plantar.....			6	1.0	6	0.7
Popliteal.....	23	10.4	102	17.2	125	15.4
Profunda femoris.....	6	2.7	19	3.2	25	3.1
branch.....	2	0.9	2	0.3	4	0.5
Tibial.....			87	14.7	107	13.1
anterior.....	5	2.3				
posterior.....	15	6.8				
Total.....	72	32.6	399	67.3	471	57.8
Head and neck:						
Carotid.....	13	5.8	48	8.1	61	7.5
Cervical, deep.....	1	0.5			1	0.1
Cirsoid.....			9	1.5	9	1.1
Lingual.....			1	0.2	1	0.1
Occipital.....			1	0.2	1	0.1
Temporal, superficial.....	2	0.9	5	0.8	7	0.9
Vertebral.....			13	2.1	13	1.6
Total.....	16	7.2	77	12.9	93	11.4

TABLE 6. DISTRIBUTION OF 814 ARTERIAL ANEURYSMS AND ARTERIOVENOUS FISTULAS—Continued

Location	Arterial aneurysms		Arteriovenous fistulas		Total cases	
	Number	Percent	Number	Percent	Number	Percent
Trunk:						
Aorta-vena cava.....			2	0.3	2	0.3
Gluteal, superior.....	2	0.9			2	0.3
Hypogastric.....			1	0.2	1	0.1
Iliac.....	4	1.7	9	1.5	13	1.5
Innominate.....	1	0.5	1	0.2	2	0.3
Mammary, internal.....			1	0.2	1	0.1
Obturator-iliac vein.....			1	0.2	1	0.1
Subscapular.....			2	0.3	2	0.3
Thoracic, lateral.....	1	0.5			1	0.1
Thoracoacromial.....	1	0.5	1	0.2	2	0.3
Total.....	9	4.1	18	3.1	27	3.4
TOTAL.....	221	100.0	593	100.0	814	100.0

While these figures do not depict the Army incidence, they do represent a large proportion of these complications. Not included are some operations that were performed overseas either because of urgent indications or in violation of the directives issued by The Surgeon General¹ which provided that Army personnel with specified types of vascular diseases and injuries would be transported to the vascular centers in the Zone of Interior.² Furthermore, the sequelae of vascular injuries are not always immediately apparent (sometimes a considerable length of time elapses before they are detectable) and data concerning these late developments are naturally not a part of this analysis. Notwithstanding, these statistics can be assumed to be reasonably complete and certainly representative of the special sequelae of vascular injuries as they were observed in the vascular centers in the Zone of Interior.

The disparity in numbers between 221 arterial aneurysms and 593 arteriovenous fistulas observed is immediately apparent. The most logical explanation for this unequal distribution is that arterial aneurysms more often present acute surgical emergencies than do arteriovenous fistulas. By their very nature aneurysms tend to become progressively larger and therefore subject to rupture. On many of them, then, surgery could not be delayed a sufficient length of time to permit the patient to be evacuated to the Zone of Interior.

¹ (1) Interview, M. D. Historians with Maj Gen Norman T. Kirk, 29 Nov 51. HD: 000.71.

(2) Interview, M. D. Historians with Maj Gen Paul R. Hawley, 18 Apr 50. HD: 000.71.

² (1) Ltr, Surg ETO, 19 Mar 44, sub: List of medical conditions which make it advisable to return personnel for hospitalization in Zone of Interior. HD: .008 Policy (ETO Professional Service File).

(2) Cfr Ltr 101, Off Surg ETO, 30 Jul 44, sub: Care of battle casualties.

While statistics are not available, experience of surgeons in foreign theaters points to the fact that numerous patients with aneurysms were operated on because of rupture or to forestall rupture.

In most patients with arteriovenous fistulas, surgery could be delayed until the patient could be transported to the Zone of Interior, for an arteriovenous fistula has no tendency to bleed externally. The very nature of this lesion, which is actually a hemorrhage from artery to vein, acts as a safety valve to prevent loss of blood and seldom presents an acute surgical emergency.

These figures, therefore, do not reflect the frequency with which such lesions occurred and cannot be used for comparative statistics. The fact that there were 593 arteriovenous fistulas and only 221 arterial aneurysms in this analysis is not an indication that the former occurred, roughly, three times more frequently.

Site and Regional Frequency

Concerning the sites of the arterial aneurysms and arteriovenous fistulas observed in the vascular centers in the Zone of Interior during World War II, no extended comment is necessary. They were identified in practically every blood vessel in the body (Table 6) but were most frequent in the axillary, brachial, and subclavian vessels in the upper extremity; in the femoral, popliteal, and tibial vessels in the lower extremity; and in the carotid and vertebral vessels in the head and neck. The largest number in any single vessel occurred in the femoral artery.

Aneurysms and arteriovenous fistulas of the vessels of the trunk were uncommon; wounds of the aorta, the renal artery, and other large and deep-seated vessels of the abdomen usually precipitated immediate death.

DIAGNOSIS

As a rule the diagnosis of aneurysms and arteriovenous fistulas resulting from battle injuries offered few difficulties; the chief problem in such cases was to demonstrate physical signs of their presence. If the lesion lay deep under heavy musculature, the characteristic pulsating mass was sometimes neither visible nor palpable but other signs which clarified the clinical picture were usually present. When a proper survey of the whole body was carried out after wounding, the diagnosis of combat-incurred arterial aneurysms and arteriovenous fistulas offered no greater difficulties in military practice than do similar lesions encountered in civilian practice.

Occasionally, especially when associated nerve injuries existed, the question arose whether the lesion was an arterial aneurysm or an abscess, and in at least one such case actual incision of the mass was undertaken before the error was realized. Occasionally, too, an arterial aneurysm or arteriovenous fistula was suspected to exist when it did not, though the following case in which this difficulty was particularly confusing is believed to be unique:

Case 1. A 30-year-old soldier was wounded in France on 2 August 1944 by shell fragments. He received penetrating wounds of the soft tissue in the left parietal region of the scalp and in the left trapezius area. There was little bleeding at the time of wounding. The wounds were debrided in an evacuation hospital and on 5 August he was admitted to a general hospital where an abnormal pulsation and bruit were noted in the left infraclavicular region. Secondary closure of the wounds was carried out on 15 August. Healing was satisfactory. A diagnosis of arteriovenous fistula was made and the patient transferred to the vascular center at Mayo General Hospital, Zone of Interior.

When first seen at this center, 24 October 1944, the patient denied numbness, paralysis, pain, excessive sweating, knew of no color or temperature changes, and had not observed any dilated veins, edema, or trophic lesions. He thought he had noted some swelling in the left clavicular area. He stated his health prior to wounding had always been good.

Examination revealed a number of dilated veins in the left pectoral and left infraclavicular areas, but otherwise inspection of the left clavicular area revealed nothing unusual. There was no visible mass, and no abnormal pulsation could be detected. There was, however, a strong pulsation palpable just beneath the midportion of the left clavicle, which was not present on the contralateral side. No thrill could be palpated but a loud systolic bruit was heard in this area. The unusually well-developed muscles in both shoulders and arms made it impossible to compress the subclavian artery above the clavicle or the axillary artery beneath it, and tests for collateral circulation therefore could not be carried out.

No color changes, edema, abnormal sweating, trophic, or neurologic changes were present in either hands or feet. The peripheral arteries were neither thickened nor tortuous. The radial, ulnar, and brachial pulses were normal and equal in the two extremities, and the venous filling time was the same (3 seconds) in both hands. Skin temperature studies revealed no significant unilateral differences.

The result of the Kahn test was negative. Roentgenograms revealed several metallic fragments in the left parietal scalp, the left side of the neck, and the left supraclavicular region.

A diagnosis of traumatic arterial aneurysm was made, either of the distal end of the left subclavian artery or of the proximal end of the axillary artery. Since it had been impossible, for the reason stated, to test the collateral circulation there was naturally a feeling of insecurity concerning its adequacy and as a precaution a preganglionic upper dorsal sympathectomy was carried out 31 October 1944.

The vascular operation was performed 30 December. The entire extent of the axillary artery was visualized by dividing the fibers of the pectoralis major and minor muscles but no aneurysm was found in the artery or in any of its branches. The axillary vein was bifid and somewhat dilated just distal to the point at which it passed beneath the clavicle, and at which the two branches joined. The clavicle could be elevated sufficiently to permit visualization and digital exploration of the subclavian vessels beneath, but neither in this area nor above the clavicle was there evidence of aneurysm or of constriction of the vessel by scar tissue. No foreign bodies were observed. The muscles were resutured and the wound closed in layers with fine black silk. No bruit was audible at the close of the procedure.

Recovery from both sympathectomy and the vascular operations was uneventful. It was noted postoperatively that the bruit was sometimes loudly audible though at other times it was absent. The prominent pulsation beneath the left clavicle persisted. The patient had a full range of motion in the left shoulder and continued to have no complaints referable to the upper extremities.

Eventually observations were made which were thought to offer an adequate explanation for these findings: The bruit was found to be present, or absent, or altered in character, according to the position of the patient and his method of breathing. It was present and intense when he stood with shoulders unsupported. It was absent when he was recumbent. When he sat with elbows resting on the arms of a chair a single short bruit was heard with

each inspiration and expiration but none was audible when respiration was held either in inspiration or expiration. When he stood or sat with his arms unsupported and hanging by his side, the bruit ceased completely during full inspiration and at the same time all arterial pulsations in the left upper extremity disappeared. Downward traction on the shoulders had no influence upon pulsation, bruit, or radial pulse. The various positions of abduction and hyperabduction, with the extremity in the plane of the body, likewise did not influence these manifestations regardless of whether the body was bent forward or backward. Similarly, strong backward thrusting of the shoulders, with the head turned to one side or the other, had no effect upon them. When the patient attempted to elevate the left shoulder against downward traction on the arm, the bruit often disappeared.

Oscillometric readings were within normal range in both arms (Table 7) except during deep inspiration when the patient was seated with his arms hanging unsupported by his sides; then oscillations ceased completely in the left arm. They also ceased when he stood with his arms hanging unsupported. When he was recumbent there was no change in the readings during forced inspiration.

TABLE 7. OSCILLOMETRIC VARIATIONS IN THE TWO ARMS AT DIFFERENT POSITIONS DURING NORMAL BREATHING AND DEEP INSPIRATION
Case of Costoclavicular Compression of Left Subclavian Artery

Position of extremity	Right		Left	
	Normal breathing*	Deep inspiration*	Normal breathing*	Deep inspiration*
Hanging, adducted.....	6	6	7	0
Hanging, shoulder thrust backward, head turned to opposite side.....	8	6	5.5	0
Abducted 90°.....	6	6	6	0
Hyperabducted over head.....	5	5	6	0

*All oscillometric readings were maximal at a pressure of 110 mm. of mercury.

The blood pressure was 128 mm. of mercury systolic and 78 diastolic in the right arm and 120 mm. of mercury systolic and 80 diastolic in the left. When the patient was standing, the venous pressure in the cephalic veins in the antecubital fossae varied from 48 to 60 cm. of water. With deep inspiration there was a rise of 5 cm. of water or more on the left side and a drop of approximately 5 cm. of water on the right.

Regardless of position, the left hand was of somewhat better color than the right. The radial and ulnar pulses were full at both wrists. In a room in which the temperature was 22° C., the skin temperature in the fingers on the right hand varied from 17.5° to 20° Centigrade. On the left side the range of variation was from 32.5° to 33.5° Centigrade. The left side of the face and the left upper extremity did not perspire; on the right side the same areas perspired normally. Ergometric studies, repeated on several occasions, revealed no essential differences in the fatigability of the two hands. Roentgenograms taken in a position of lordosis revealed some narrowing of the space between the clavicle and the first rib on the left with inspiration, but the interpretations were inconclusive.

From these various observations it was decided that the physical signs which this patient presented could be explained by compression of the subclavian vessels on the left between the first rib and the clavicle. When he stood with arms unsupported, partial compression of the vessels occurred and there was a resulting loud systolic bruit. When he was recumbent, compression did not occur and there was no bruit. Full inspiration in the

standing or sitting position caused sufficient compression of the vessels to shut off completely all flow of blood to the left upper extremity. With normal respiration this phenomenon did not occur.

Since the patient had no complaints and had ample circulation under ordinary conditions, further operative interference was not thought justified and he was returned to duty.

Comment. For a number of years it has been well known that certain vascular and neurologic symptoms in the upper extremity may result from structural abnormalities or be associated with positional changes. Particularly well known are the scalenus anticus syndrome and the clinical pictures associated with cervical ribs and with tendinous or cartilaginous bands extending from rudimentary cervical ribs or transverse processes. Also well known are the symptoms resulting from compression of the subclavian vessels and the brachial plexus between the first rib and the clavicle, and neurovascular complaints resulting from the relatively normal obliteration of arterial pulsation in the upper extremity in various positions of hyperabduction when they are maintained for any length of time.

The case just described differs from previously reported cases of costo-clavicular compression. Although the patient had no subjective complaints, he presented physical findings which pointed to the diagnosis of aneurysm. Prior to operation, in fact, no doubt existed concerning the diagnosis, partly because the patient had sustained a wound which might have injured the subclavian or axillary artery and partly because of the signs present. Furthermore, aneurysms of considerable size in this area may exist in the absence of a pulsating mass, without thrill, and with only moderately strong pulsations and moderately intense bruits. In this case there was no mass and no thrill could be felt, but pulsation was prominent and the bruit was intense.

It is unfortunate that because of a diagnostic error this patient was subjected to two unnecessary surgical procedures, but under the circumstances it is difficult to see how they could have been avoided since, so far as can be determined, this particular syndrome had never before been reported and therefore was not suspected. The excessive development of the arm and shoulder muscles prevented testing of the collateral circulation, and preoperative sympathectomy was regarded as desirable for two reasons: First, arterial aneurysms, in contrast to arteriovenous fistulas, provide notoriously poor stimuli for the development of a collateral circulation. Second, the possibility that surgical cure of an aneurysm will entail ligation of the involved artery always exists when an operation of this type is undertaken. It is true that the subclavian and axillary arteries can often be severed with relative impunity, but it is equally true that gangrene may follow such a procedure.

Since the question might be raised as to whether the clinical picture was the same before and after the operation, it can be said that nothing was done during the exploratory operation which could have altered the regional anatomy and physiology, and that the postoperative findings offer adequate explanation of the picture presented before operation.

THERAPY

In a large number of the arterial aneurysms and arteriovenous fistulas observed at the vascular centers during World War II operative cure (Tables 8-9) was possible, partly because of the very considerable number of these lesions from which cases for this procedure could be selected, partly because of a deliberate effort to increase the number of indications for operation, and partly because competent vascular surgeons had been chosen to head these centers and carry out the delicate and difficult procedures involved. Otherwise, the therapy of these vascular lesions did not differ from that which would be employed under similar circumstances in civilian practice.

TABLE 8. TECHNIQUES OF OPERATIVE TREATMENT IN 209 ARTERIAL ANEURYSMS

Location	Endo-aneurysmorrhaphy	Excision	Proximal ligation	End-to-end anastomosis	Total cases
Upper extremity:					
Axillary	10	24	1		35
Brachial	16	30		1	¹ 47
Radial	7	5			12
Subclavian	2	10	1		² 13
Ulnar	3	4			7
Lower extremity:					
Femoral	14	4			³ 18
Gastrocnemius, muscle branch		1			1
Peroneal	2				2
Popliteal	19	2			⁴ 21
Profunda femoris	6				6
branch	2				2
Tibial, anterior	5				5
Tibial, posterior	7	8			⁵ 15
Head and neck:					
Carotid		5	8		⁶ 13
Cervical, deep	1				1
Temporal, superficial		2			2
Trunk:					
Gluteal, superior	2				2
Iliac	2	1	1		4
Innominate	1				1
Thoracic, lateral		1			1
Thoracoacromial		1			1
Total	99	98	11	1	209

This total does not include—

- ¹ 1 aneurysm in which cure occurred spontaneously.
- ² 2 aneurysms in which method of management was not stated.
- ³ 2 aneurysms in which cure occurred spontaneously.
- ⁴ 3 aneurysms, 2 in which methods of management not stated and 1 in which spontaneous cure occurred.
- ⁵ 2 aneurysms in which cure occurred spontaneously.

TABLE 9. TECHNIQUES OF OPERATIVE TREATMENT IN 585 ARTERIOVENOUS FISTULAS

Location	Arterial repair	Quadruple ligation and excision	Ligation alone (mass, proximal, distal, or proximal and distal)	Total cases
Upper extremity:				
Axillary.....		32		32
Brachial.....		29		¹ 29
Cervical, transverse.....		1		² 1
Humeral, posterior circumflex.....		1		1
Interosseous, common.....		1		1
Radial.....		2		2
Scapular, transverse.....		2		2
Subclavian.....	1	16	1	³ 18
Ulnar.....		0		0
Lower extremity:				
Calf, to muscles of.....		4		4
Circumflex, lateral.....		1		1
Femoral.....	16	124	1	⁴ 141
Geniculate.....		5		5
Gluteal, inferior.....		1		1
superior.....		3		3
Peroneal.....		24	1	25
Plantar.....		6		6
Popliteal.....	11	91		102
Profunda femoris.....		19		19
branch.....		2		2
Tibial.....		87		87
Head and neck:				
Carotid.....	5	29	14	³ 48
Cirsoid.....		9		9
Lingual.....		1		1
Occipital.....		1		1
Temporal, superficial.....		3	2	5
Vertebral.....		8	5	13
Trunk:				
Aorta-vena cava.....	1			1
Hypogastric.....		1		1
Iliac.....		9		9
Innominate.....			1	1
Mammary, internal.....		1		1
Obturator-iliac vein.....		1		1
Subscapular.....		2		2
Thoracoacromial.....		1		1
Total.....	34	526	25	585

This total does not include:

¹ 2 fistulas, 1 in which method of management not stated, and 1 in which spontaneous cure occurred.

² 1 fistula in which method of management not stated.

³ 1 fistula in which spontaneous cure occurred.

⁴ 3 fistulas, 1 in which methods of management not stated, and 2 in which spontaneous cure occurred.

Most of the 221 arterial aneurysms were treated by endoaneurysmorrhaphy (99 cases) or excision of the aneurysm (98 cases). Most of the 593 arteriovenous fistulas were treated by quadruple ligation and excision (526 cases). The techniques used were almost without exception those employed for these lesions when encountered in civilian practice.

Anesthesia. Fractional spinal analgesia was preferred for operations on the lower extremities since all procedures in this region were likely to be long and tedious. Thiopental sodium anesthesia administered intravenously, and supplemented as necessary by nitrous oxide and oxygen, was preferred for operations on other parts of the body. In operations about the neck and head an intratracheal tube was usually introduced to ensure smooth anesthesia and maintain an open airway.

Almost without exception there were no complications of any consequence attributable to anesthesia at any of the vascular centers. This is a notable achievement since over half of the operations required 3 hours or longer and some lasted 8 hours. The advantages of the types of anesthesia selected are apparent for operations of such length.

PREOPERATIVE AND POSTOPERATIVE CARE

Preoperative Care

The status of patients with arterial aneurysms who are encountered in civilian practice may or may not be good. Often it is not good because of advancing age, the presence of organic cardiac or cardiorenal disease, hypertension, or similar complications. The great majority of aneurysms encountered in civilian practice have been brought about by an underlying disease and the surgical risk must be estimated with this in mind. Arteriovenous fistulas, on the other hand, are almost without exception of traumatic origin and the patient is quite likely to be a good surgical risk.

The great majority of patients with arterial and arteriovenous fistulas treated at the vascular centers in the Zone of Interior during World War II were young men in excellent physical condition. They had no background of disease, cardiac or otherwise. Some patients it is true had other injuries, but for the most part the vascular lesion was the only disability, or the major disability, and the surgical risk had to be estimated principally on the basis of this lesion.

Preoperative preparation, therefore, was generally limited to tests of the circulatory status of the affected part and the institution of methods to improve the circulation. The usual routine was to keep patients with arterial aneurysms under close observation in the hospital until the proper time for operation arrived. If no contraindications existed they were permitted to walk, but their activities were restricted to those which did not require strenuous effort. Patients with arteriovenous fistulas, if they showed no evidence of cardiac enlargement, and many of them did not, were usually allowed to

leave the hospital on furlough but were required to return at regular intervals for checkups until the appropriate time for operation arrived.

Since surgery of vascular lesions of these types had to be delayed to permit the development of an adequate collateral circulation, any danger of infection from the original wound had long since passed before the operation was undertaken. Preoperatively, therefore, chemotherapeutic and antibiotic agents were not administered.

Patients whose arterial lesions had produced cardiac dilatation of any degree or who presented evidence of actual or impending cardiac failure were prepared for operation as they would have been under similar circumstances in civilian practice.

When indicated, an internist was called in consultation. Physical therapy was employed as indicated before as well as after operation. It was of the greatest usefulness in patients in whom contractures had developed as a result of disuse, or in whom concomitant lesions of nerve or bone, or nerve and bone, complicated the vascular lesion.

Postoperative Care

Dressings covering the operative wound were always small and simple and served only to protect the incision. However, when pressure for the obliteration of an aneurysmal sac was indicated an elastic bandage was employed. In order to prevent swelling it was so applied as to cover the whole extremity from toe to thigh or from fingers to axilla. Pressure was maintained until the patient was ambulatory or until there was no longer any evidence of an accumulation of fluid in the wound.

Patients operated on for lesions of the smaller vessels, particularly vessels of the upper extremity, were allowed to be ambulatory within 24 hours of operation provided there were no contraindications. When their lesions involved larger blood vessels they were kept in bed for a period of 10 days to 2 weeks until the wound was well healed.

Patients with a considerable degree of cardiac dilatation or with evidence of cardiac failure required special treatment. A longer period of bed rest was usually necessary and the return to normal activities was always graduated and cautious. Medication depended upon the indications of the special case. Treatment was usually carried out in cooperation with the internist.

Chemotherapy and Antibiotic Therapy

The sulfonamide drugs (antibiotics were not available in the first months of operation of the vascular centers) were used in relatively few cases. When such treatment was regarded as necessary, the agents were given in standard dosages. They were never administered for purely prophylactic reasons and sulfanilamide and similar preparations were never placed in wounds.

When penicillin became available, however, it was administered routinely as a prophylactic measure. It was given (intramuscularly, as a rule) immediately after operation and continued until it was thought that all danger of

infection had passed. The usual dose was 30,000 units every 3 hours for a period of 5 days. Reactions were minimal, and limited to urticaria and fever. They were observed only occasionally and in every instance cleared up as soon as therapy was discontinued.

Streptomycin did not become available until the vascular centers were in process of deactivation. It was not regarded as indicated in any instance of aneurysm or arteriovenous fistula then under observation.

PREOPERATIVE COMPLICATIONS

More than half (447) of the 814 vascular injuries in this series were associated with injuries of the nerves, bones, or soft tissues (Tables 10 and 11). Frequently these injuries were of an extremely serious character and introduced problems of repair which required patience and ingenuity for their solution. These considerations are discussed in detail in the volumes of the history devoted to neurosurgery and orthopedic surgery and will not be repeated here.

Other preoperative complications, with the exception of 2 cases of major causalgia in connection with arterial aneurysms, were confined to arteriovenous fistulas. They consisted of major causalgia in 7 cases; gangrene, which was seldom extensive, in 13 cases; gas gangrene in 2 cases, in both of which it was readily controlled; and *Streptococci viridans* bacteremia in 1 case.

The single instance of *Streptococcus viridans* septicemia in this series is worth recording in detail for two reasons: (1) it originated in vegetations in a femoral arteriovenous fistula, and (2) it was cured by surgical excision of the fistula. A number of instances of septicemia of this origin have been recorded but, so far as can be determined from a survey of the literature, there are on record to date only three instances of cure of the bloodstream disease by surgical removal of the arteriovenous fistula. The first of these cases, reported by Hamman and Rienhoff³ in 1935, was an arteriovenous fistula of the external iliac vessels which had resulted from a rifle injury 17 years earlier. The second, reported by Touroff, Lande, and Kroop⁴ in 1942, was an arteriovenous fistula of the profunda femoris vessels combined with a saccular aneurysm which had resulted from a gunshot wound 9 years earlier. The third, reported by Lipton and Miller⁵ in 1944, was a femoral arteriovenous fistula of 15 years duration which also had resulted from an accidental gunshot injury.

Case 2. This 26-year-old soldier was wounded (after 18 months in the Southwest Pacific theater) on Leyte 21 December 1944. He received penetrating grenade-fragment wounds in the right thigh, left arm, left chest, and left thigh. There was considerable bleeding from the right thigh wound, but it was controlled by a compression bandage. His wounds were debrided at a mobile surgical hospital and he was evacuated to a numbered general hospital. There, on about 18 January 1945, he called the attention of the attending medical

³ Hamman, L., and Rienhoff, W. F., Jr.: Subacute *Streptococcus viridans* septicemia cured by excision of an arteriovenous aneurysm of the external iliac artery and vein. *Bull. Johns Hopkins Hosp.* 57: 219-234, Oct 1935.

⁴ Touroff, A. S. W.; Lande, H., and Kroop, I.: Subacute *Streptococcus viridans* septicemia cured by excision of an infected traumatic arteriovenous aneurysm. *Surg., Gynec. & Obst.* 74: 974-982, May 1942.

⁵ Lipton, S., and Miller, H.: *Streptococcus viridans* septicemia—subacute bacterial endarteritis of an arteriovenous aneurysm. *J. A. M. A.* 126: 766-769, Nov 1944.

officer to a "purring" sensation in the right thigh which he had first noted on the third day after injury. Examination disclosed the classical signs of an arteriovenous fistula and he was evacuated by air to the Zone of Interior.

The patient was admitted to the vascular center of Mayo General Hospital, 11 February 1945. His past history was noncontributory (cardiovascular history entirely normal) except for recurring attacks of tonsillitis. Within the last 14 months he had had 3 attacks of malaria. His wounds had healed uneventfully and he had no symptoms other than the "purring" sensation in the right thigh and a little numbness along the medial aspect of the knee.

TABLE 10. ASSOCIATED INJURIES IN 159 ARTERIAL ANEURYSMS

Location	Nerve injury	Fracture	Extensive soft tissue damage	Total
Upper extremity:				
Axillary.....	32	2		34
Brachial.....	40	5		45
Radial.....	6	4	1	11
Subclavian.....	9	2		11
Ulnar.....	5	2		7
Total.....	92	15	1	108
Lower extremity:				
Femoral.....	2	3		5
Peroneal.....		1	1	2
Popliteal.....	6	3	3	12
Profunda femoris.....		2	1	3
branch.....		1		1
Tibial, anterior.....	1	2		3
posterior.....	4	7	1	12
Total.....	13	19	5	38
Head and neck:				
Carotid.....	7	2		9
Total.....	7	2		9
Trunk:				
Iliac.....	2	2		4
Total.....	2	2		4
TOTAL.....	114	38	7	159

TABLE 11. ASSOCIATED INJURIES IN 288 ARTERIOVENOUS FISTULAS

Location	Nerve injury	Fracture	Extensive soft tissue damage	Total
Upper extremity:				
Axillary.....	13	5	4	22
Brachial.....	20	2	1	23
Cervical, transverse.....	1			1
Humeral, posterior circumflex.....	1			1
Interosseous, common.....	1			1
Scapular, transverse.....		1		1
Subclavian.....	8	2		10
Ulnar.....	1	2		3
Total.....	45	12	5	62
Lower extremity:				
Calf, to muscles of.....	1			1
Circumflex, lateral.....	1			1
Femoral.....	27	22	11	60
Gluteal, inferior.....	1			1
superior.....		1		1
Peroneal.....	9	10	2	21
Plantar.....	1	3		4
Popliteal.....	24	13	4	41
Profunda femoris.....	3	3	2	8
branch.....		1		1
Tibial.....	22	20	3	45
Total.....	89	73	22	184
Head and neck:				
Carotid.....	18	11		29
Occipital.....	1			1
Temporal, superficial.....	2			2
Vertebral.....	6	3		9
Total.....	27	14		41
Trunk:				
Iliac.....	1			1
Total.....	1			1
TOTAL.....	162	99	27	288

He denied having had edema, cyanosis, coldness, pain, or weakness in the right lower extremity.

A general physical examination revealed nothing remarkable except for the generalized yellowing of the skin commonly seen in patients who have had prolonged atabrine therapy. The sclerae were normal in color. There was no tortuosity or thickening of the peripheral arteries and no evidence of cardiac enlargement. The heart sounds were normal and there were no murmurs.

Examination of the right thigh revealed an abnormal pulsation over the course of the femoral vessels in the proximal third, associated with a continuous thrill and a loud, continuous bruit which could be heard down to the knee and up into the right lower quadrant of the abdomen. Both thrill and bruit could be obliterated by direct pressure over the femoral vessels about 15 cm. below the inguinal ligament. When this maneuver was carried out the pulse rate slowed from 76 to 52 beats per minute and blood pressure rose from 124 mm. of mercury systolic and 64 diastolic to 138 mm. of mercury systolic and 86 diastolic. When atropine was administered before compression of the femoral vessels, blood pressure changes were of the same magnitude as before but the pulse decreased by only 8 beats per minute. The dorsalis pedis and posterior tibial pulses were normal in both feet and the venous filling time was the same on both sides. In a room at a temperature of 22° C. the skin temperature of the toes on the right foot varied from 19° to 20° C. and on the left foot from 21° to 21.5° Centigrade. After 5 minutes of total arterial occlusion, and with the fistula completely compressed by digital pressure, reactive hyperemia began in the toes on the right foot in 20 seconds and was complete and full in the foot in 90 seconds.

The electrocardiogram was normal except for a QRS complex of 0.12 seconds duration. Roentgenograms showed no cardiac enlargement. The frontal cardiac area was 146 sq. cm. (Fig. 11A) as compared with a predicted frontal area of 143 sq. cm. for a man of the patient's weight and height.

A diagnosis of femoral arteriovenous fistula, with collateral circulation adequate for surgical extirpation was made. On 1 March 1945, the 17th day of hospitalization, and before a date for operation had been set, the patient had chills and fever which recurred in 48 hours. The clinical diagnosis of malaria was confirmed by a blood smear positive for *Plasmodium vivax*. The recurrence was promptly controlled by atabrine and after the blood smears were reported as negative the patient was permitted to leave the hospital on furlough. When he returned 5 April 1945, he stated that shortly after he left the hospital he had had a recurrence of chills and fever, this time associated with a sore throat, and that a week later he had experienced abdominal soreness and a mild but persistent diarrhea. He had also suffered a moderate loss of appetite. He regarded the illnesses as a recurrence of malaria and had taken atabrine, but without results. He had been confined to bed for most of his 3-week furlough and had lost 16 pounds in weight.

Examination on his readmittance to hospital revealed some tenderness in the region of the transverse colon and a barely palpable spleen. Stool examinations revealed infection by both hookworm and amebae. Appropriate treatment for these parasites resulted in prompt disappearance of the intestinal symptoms.

The patient's temperature had been 102° F. when he was readmitted to the hospital, and though it did not rise above 99.2° F. for the next 3 days, it was higher the following day (Chart 18) and remained abnormal until after administration of penicillin. Atabrine was discontinued 14 April because blood smears had been reported negative for malaria parasites since 3 March. On 16 April the soldier had a severe chill followed by a temperature rise to 102.4° F., and 3 days later a similar episode occurred though at this time the temperature rose only to 101.3° Fahrenheit.

Following the chill and temperature elevation the patient became dyspneic and orthopneic and complained of pain and tenderness over the sternum. Within a few hours the chest pain shifted laterally and became localized in the left fourth interspace in the anterior axillary line. There was marked tenderness in this area. Examination of the chest re-

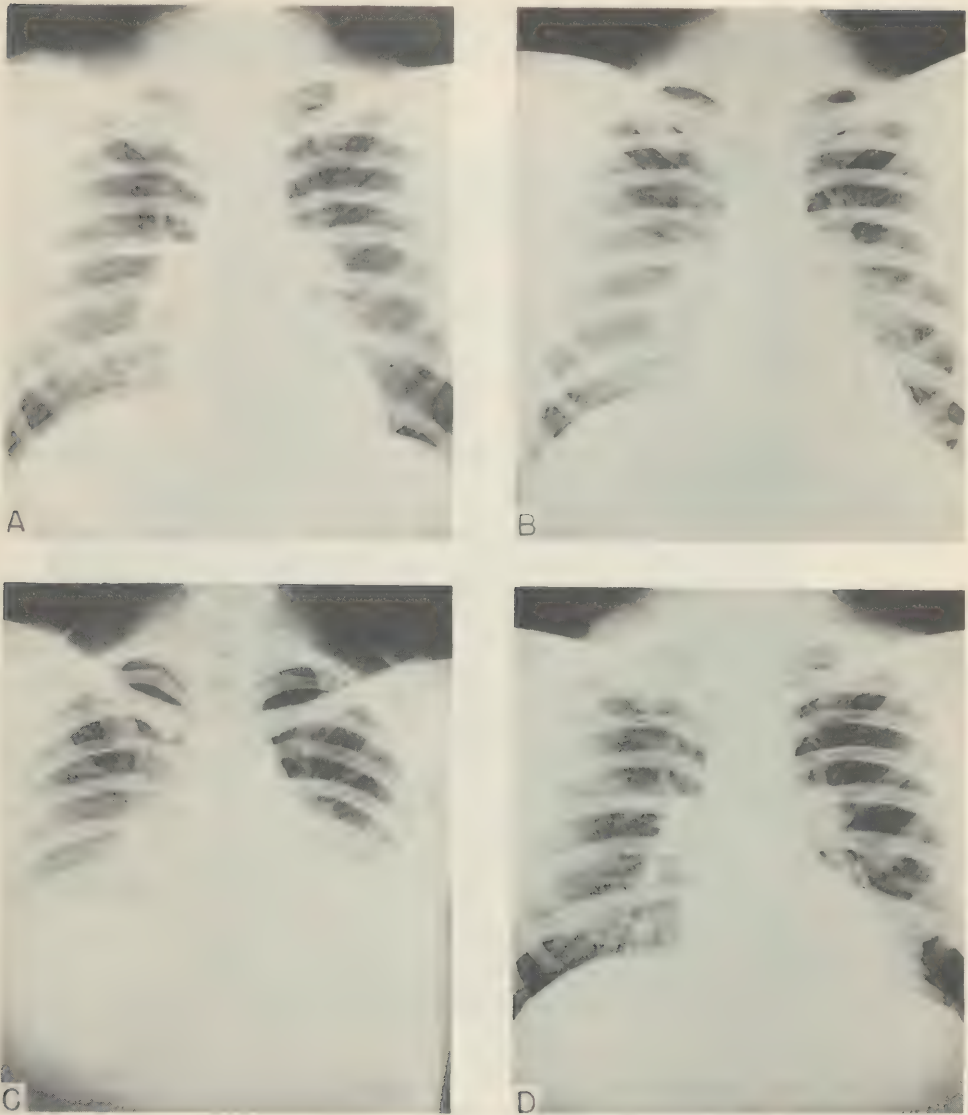


Figure 11. Roentgenograms showing change in heart size and evidence of pulmonary infarction.
A. 13 February 1945, heart size is normal. Frontal cardiac area 146 square centimeters.
B. 5 April, heart size has increased. Frontal cardiac area 168 square centimeters.
C. 23 April, heart size difficult to estimate because of pathologic changes in the lungs and elevation of diaphragm. There is increased density in the left lower lung field from pulmonary infarction. D. 4 June, 6 weeks after operation the heart size is normal, the lung field is clear. (The method of Ungerleider and Gubner was used in computing the size of the heart.)

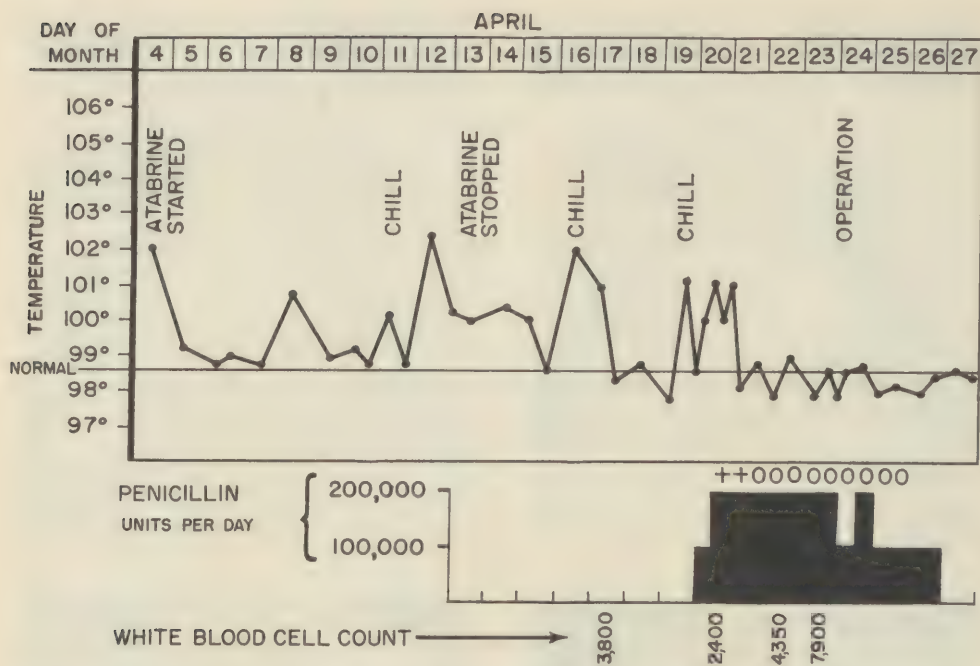


Chart 18. Temperature chart of patient with *Streptococcus viridans* septicemia preceding and following operation.

vealed (for the first time) a soft, blowing, nontransmitted systolic murmur in the third interspace to the left of the sternum. The first heart sound was roughened and the apical impulse was displaced 3 cm. to the left of the midclavicular line. Over the left lower lobe posteriorly, breath sounds were absent, crepitant rales were heard, and there was marked dullness to percussion. The temperature was now 101.2° F., the pulse was 120 beats per minute, and the respirations were 20 per minute. On the basis of the clinical findings a tentative diagnosis of pulmonary infarction was made.

Roentgenograms made on 5 April revealed increased density which obliterated the left lower lung field, a finding compatible with a diagnosis of pulmonary infarction. The frontal cardiac area, which had been 146 sq. cm. on 13 February, had increased to 168 sq. cm. by 5 April—17 percent above normal (Fig. 11B). By 23 April, 4 days after the development of chest symptoms and signs, it was approximately 174 square centimeters. A more exact measurement was not possible because of the pulmonary changes (Fig. 11C). On the same day an electrocardiogram showed sinus tachycardia with slight slurring of QRS in the third lead and a QRS complex of from 0.10 to 0.11 seconds duration.

The persistence of intermittent chills and fever after a diagnosis of malaria had been eliminated, together with the clinical and roentgenographic signs suggestive of pulmonary embolism, pointed to a diagnosis of septicemia, the most likely source of which was thought to be vegetations within the femoral arteriovenous fistula. Blood taken for culture on 20 April was reported 24 hours later as positive for *Streptococcus viridans*. At this time leukocytes numbered 12,400 per cubic millimeter of blood, with a differential count showing 28 percent lymphocytes. The concentration of hemoglobin was 11.9 gm. per 100 cc. of blood, the prothrombin time 30 seconds, and the hematocrit reading 36 percent. There was no increase in tenderness to pressure over the arteriovenous fistula. No petechiae were observed.



Figure 12. Kodachrome of specimen removed at operation viewed from venous side of arteriovenous fistula. Note numerous vegetations along margins of fistula.

The patient, whose expression was one of grave apprehension, was obviously acutely ill. Dilaudid (dihydromorphinone hydrochloride) was given for the relief of chest pain. Penicillin, begun on 19 April, was administered intramuscularly in doses of 25,000 units every 3 hours for 3 days and then in doses of 12,500 units every 3 hours for the next 3 days. Blood taken for culture on 21 April was again reported positive for *Streptococcus viridans* but repeated cultures for the next 6 days showed no growth of organisms. The patient became afebrile 48 hours after penicillin was begun and there were no further chills (Chart 18). On 24 April, immediately after an intravenous injection of 100,000 units of penicillin, the patient was operated upon.

With the patient under spinal analgesia a longitudinal incision about 12 cm. long was made over the course of the femoral vessels beginning about 6 cm. below the inguinal fold. The fascia was divided and the sartorius muscle retracted. A great deal of scarring was observed in the region of the vessels. The femoral artery, which was about normal in size, and the femoral vein, which was dilated to a diameter of about 2 cm., were isolated above and below the fistula. A continuous thrill was present. The saphenous and the femoral nerves which were adherent to the vessels were dissected free without injury. The artery and vein were divided above and below the fistula and the stumps transfixed with silk. A large fistula almost 1.5 cm. in diameter communicating between the artery and vein was excised. The wound was closed in layers with interrupted silk sutures. The operative procedure was carried out without difficulty and the patient's condition was good throughout.

Examination of the excised specimen (Fig. 12) revealed a large arteriovenous fistula almost 1.5 cm. in diameter. The margins of the fistula were studded with minute small vegetations. Cultures made directly from these vegetations revealed a heavy growth of *Streptococcus viridans*, although at the time of operation blood cultures had been reported as negative for these organisms. Histologic examination revealed that these vegetations were literally studded with cocci (Fig. 13).

The patient's postoperative course was uneventful. He remained afebrile, and his pulse and blood pressure were within normal range. The bruit and thrill were no longer present in the area of the fistula and the temperature and color of the right leg were normal. The patient was allowed out of bed on the fourth day. For a few days thereafter he complained of a pulling sensation in the left chest on deep inspiration but he had no dyspnea and orthopnea and this minor discomfort rapidly disappeared. The signs of infarction in the left lower lobe gradually disappeared and 6 weeks after operation a clinical and roentgenologic examination revealed no abnormalities in this area. The size of the heart returned to normal (Fig. 11D).

When the patient was first discharged from hospital he experienced slight edema of the right leg after it had been in a dependent position for a long period. When examined 5 July 1945, no edema was present and he stated that there had been no evidence of it for a week; at this time he was wearing an elastic stocking. His only complaint was a sense of fatigue in the calf after he had walked for half a mile. The feet showed no abnormal color changes. The posterior tibial and the dorsalis pedis pulses were present on both sides but were reduced in volume on the right. In a room in which the temperature was 25.5° C. the temperature of the toes on both feet varied between 29° and 30° Centigrade. The oscillometric reading in the distal thigh was 2.5 at 70 mm. of mercury on the right and 6 at 120 on the left. In the calf the oscillometric value was 3 at 60 mm. of mercury on the right side and 7.5 at 90 on the left. In the ankle it was 2 at 70 mm. of mercury on the right and 5 at 80 on the left. The pulse was 56 beats per minute and the blood pressure 128 mm. of mercury systolic and 70 diastolic.

The patient was reexamined about 3 weeks later. The elastic support had not been worn in the interim and he had experienced no edema. After a walk of about 1½ miles he stated he had a sense of tightness in the right calf, but the discomfort was not great enough to make him cease walking. There had been no recurrence of fever, chills, or pulmonary and cardiac symptoms. He looked well and was apparently in excellent general condition.

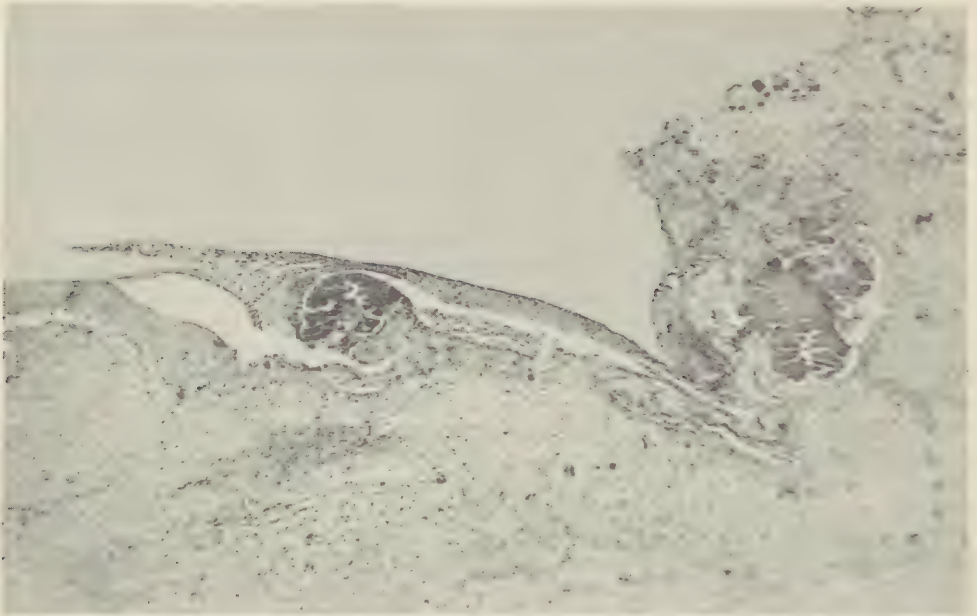


Figure 13. Photomicrograph of portion of excised arteriovenous fistula showing two bacteria-studded vegetations (H. and E. stain, high power magnification). The dark-staining areas are masses of cocci. Cultures of these vegetations yielded a pure growth of *Streptococcus viridans*.

Comment. Transient *Streptococcus viridans* bacteremia is not infrequent in the course of upper respiratory or sinus infections, or following the extraction of infected teeth. Presumably such transient bacteremia is the original source of infection in cases of subacute bacterial endocarditis. It is therefore significant that the patient had had recurrent attacks of tonsillitis since childhood and had had a severe attack associated with pharyngitis and accompanied by chills and fever about a month before the diagnosis of septicemia was made. It is quite conceivable that this attack resulted in infected vegetations within the arteriovenous fistula.

Although this patient had a multiplicity of other diseases (tonsillitis and pharyngitis, malaria, hookworm, and amebic infection) the recognition of *Streptococcus viridans* infection was not long delayed. The diagnosis was relatively easy despite the coincident malaria because of the severe chills and fever, the signs and symptoms of pulmonary infarction, and the presence of an arteriovenous fistula. The findings on blood culture merely confirmed the clinical suspicion.

The rapid increase in cardiac size which occurred in this case (Fig. 11A-C) was probably the direct result of the altered circulatory dynamics produced by the presence of the large femoral arteriovenous fistula. Similar increases

were observed in other patients with similar lesions during the period of observation prior to excision of the fistula.

This case illustrates the necessity of bearing in mind the presence of arteriovenous fistula when looking for a source of infection in instances of *Streptococcus viridans* septicemia. It also exemplifies the dramatic cure which can be achieved in such instances by surgical removal of the defect. The patient was treated with penicillin over a 6-day period and the blood stream was thus rendered sterile prior to operation, but the heavy growth of *Streptococcus viridans* obtained from within the fistula after it had been removed is evidence that the apparent cure would not have been permanent.

POSTOPERATIVE RESULTS

The criteria for a successful operation were considered fulfilled if the objective evidences of the lesion which had been present before operation had disappeared after operation and there was no evidence of recurrence during the postoperative period of hospitalization. These standards were deemed adequate since the period of hospitalization is much longer in military than in civilian practice and since any recurrence of aneurysmal lesions becomes evident rather promptly.

Of the 801 operations performed at the vascular centers during World War II (in 13 instances in this series of 814 cases, surgery was unnecessary because spontaneous cures occurred) there were only 4 fatalities, 10 failures, and 36 instances of complications following operation. Much of the success can be attributed to the youth and generally good circulatory status of the patients in whom these lesions occurred, but other factors contributed and are worthy of note. The thorough preoperative examination to which each patient was submitted and the detailed evaluation of his vascular status established the fact that the operation was being performed at the optimum time on a patient whose vascular status was as good as it could be made. Furthermore, the surgeons who performed the operations in these centers were men preeminent in the field of vascular surgery and had at their disposal the appropriate precision instruments and other necessary equipment.

It is possible, too, that the adjunct use of certain measures, particularly anticoagulant therapy (see Chapter X) and sympathectomy (see Chapter XI) played some part in the results. On the other hand, neither of these methods was employed at one center (Ashford) where the results were quite as good as those obtained at the other centers. The conclusion seems warranted, therefore, that while these methods may be useful in selected cases, they are certainly not indispensable.

Complications

The number of postoperative complications in this series (36) is remarkably small when weighed against the number of operations (801) performed for aneurysms and arteriovenous fistulas. These complications included:

1. Nineteen instances of wound infection: 12 in arteriovenous fistulas and 7 in aneurysms. In 1 arterial aneurysm the infection progressed to necrosis.
2. Four instances of hemorrhage: 3 in arteriovenous fistulas and 1 in an aneurysm.
3. Five instances of hematomas in the wound: 4 in arteriovenous fistulas and 1 in an aneurysm.
4. One instance of mediastinal abscess in an arteriovenous fistula.
5. Three instances of major causalgia: 2 in aneurysms and 1 in an arteriovenous fistula.
6. Two instances of hemiplegia: 1 in an aneurysm and 1 in a fistula.
7. Two instances of gangrene, both in arteriovenous fistulas.

Failures

There was immediate evidence of failure following 10 operations performed at the vascular centers. The failures occurred in—

1. Two arterial aneurysms, both in the subclavian artery.
2. Eight arteriovenous fistulas: 1 in the aorta and vena cava, 4 in the carotid, 1 in the superficial temporal artery, and 2 cirroid aneurysms.

Fatalities

Four deaths occurred in the 801 cases treated surgically at the vascular centers. The distribution of the lesions was as follows:

1. Aneurysm of the deep cervical artery.
2. Aneurysm of the subclavian artery.
3. Arteriovenous fistula between subclavian artery and vein.
4. Arteriovenous communication between the internal carotid artery and the cavernous sinus.

The details of these cases are as follows:

Case 3. A 22-year-old soldier was operated on 4½ months after injury for a large aneurysm on the left side of the neck which was causing a good deal of pain. Intratracheal anesthesia was used. After the carotid artery had been isolated and a tape had been placed about it, temporary occlusion of the vessel did not end the pulsation in the area. Compression of the vertebral and subclavian vessels was equally ineffective. It was apparent from these phenomena that some one of the small branches of the carotid artery was the site of the aneurysm, but the sac was so large that the vessel could not be isolated.

A cautious attempt was therefore made to free the sac with the idea of isolating the vessel when it was elevated. During this attempt, however, the sac was accidentally entered. The opening into the artery could easily be occluded by introduction of the finger, but each time that suture transfixion of the opening was attempted a considerable amount of blood was lost. Although the patient had been receiving plasma and blood throughout the procedure, he was now discovered to be in shock and in a matter of moments, pulseless. His blood pressure could not be determined and for several minutes breathing had to be maintained by artificial respiration.

It was finally possible to suture the artery within the aneurysm and there was some improvement in his condition following the introduction of more blood, but he never regained

consciousness. Convulsions ensued and death occurred 24 hours after operation. Necropsy revealed diffuse acute and anoxic edema and necrosis of the middle layer of the right cerebral cortex. The vessel involved proved to be the deep cervical artery.

Comment. This death should not have occurred. An inexperienced anesthetist gave the anesthetic and the surgeon had no warning of the patient's condition until it had become irreversible. Had the proper warning been given, the operation could probably have been terminated quickly and without further loss of blood by packing the sac and suturing the aneurysm, or bleeding could have been controlled by pressure until the patient's status permitted the loss of more blood while another attempt was made to suture the vessel.

Case 4. A 24-year-old soldier was operated on 11 months after injury for a large subclavian arterial aneurysm which was partly in the neck and partly in the mediastinum. Intratracheal anesthesia was used. Excellent exposure was obtained by resecting the inner portion of the clavicle and splitting the sternum. The subclavian artery was ligated proximal and distal to the opening in the sac.

Although there was no further bleeding, the sac continued to pulsate feebly and the introduction of a needle revealed arterial blood under pressure. This blood was obviously coming from the vertebral artery which was the only vessel trapped between the two ligatures. The aneurysm was so large that access to the vertebral artery in its free portion was completely prevented. The sac was therefore gradually freed without special difficulty. When the posterior aspect had been dissected free almost to the point of the opening, the sac was quickly opened and back bleeding from the vertebral artery readily controlled. At this time the wound was dry and the major portion of the sac could be excised.

The patient had received blood throughout the operation and his systolic blood pressure had never fallen below 90 mm. of mercury. Except that he was notably drowsy after operation, his condition seemed good. The blood pressure was constantly in the neighborhood of 130 mm. of mercury systolic and 80 diastolic and the pulse, which was of good volume, in the neighborhood of 100 beats per minute.

The night after the operation the patient woke suddenly and complained of a severe occipital headache. Shortly afterward he became stuporous and then comatose, and death occurred about noon the following day. There was a rapid rise of both temperature and pulse rate during the night and just prior to death they were greatly elevated.

Necropsy revealed encephalomalacia of the left cerebellum with some diffuse old subarachnoid hemorrhage and scarring. No thrombus could be demonstrated in the vertebral artery or in the circle of Willis. The right vertebral artery and both carotid arteries were intact.

Comment. The course of events in this case was unexpected and cannot be explained. In retrospect, it seems that the management of the case was correct and that the operative procedure was properly performed.

Case 5. A 20-year-old paratrooper was stabbed with a knife in the left infraclavicular region. Bleeding, which was profuse, was controlled by pressure but neither formal debridement nor exploration was carried out; the wound was merely closed with sutures. Slight drainage from the wound had continued for approximately 3 weeks after the injury. Then complete healing occurred. Within a short time after the injury the patient became conscious of a buzzing sensation in the left upper chest and in the region of the shoulder.

Two and one-half months after injury he was admitted to a vascular center in the Zone of Interior. Examination given at the time of admittance revealed the typical symptoms and signs of an arteriovenous communication in the first part of the subclavian vessels. There were no trophic changes in the left upper extremity, also no evidence of cardiac decompensation.

At operation, which lasted 8 hours, the left clavicle was resected, and the median half of the bone removed, the first portion of the subclavian artery was then identified and the fistula located between the subclavian artery and vein. It lay so near the aortic arch that its isolation was extremely difficult and on several occasions brisk bleeding was encountered, though it could always be satisfactorily controlled by means of sutures or ligatures.

Convalescence was satisfactory until the fourth postoperative day when it became apparent that the wound was infected. Six days later a secondary hemorrhage occurred from the wound; it was finally controlled in the operating room by suture and ligature. For the next 5 days recovery was uneventful. Then bleeding from the wound recurred. This time the attempt to control the hemorrhage by surgery was ineffective for all the structures were so friable that isolation of the bleeding vessel was not possible and the patient died on the operating table. A continuous transfusion of whole blood was given from the time he was placed on the operating table until death occurred.

Comment. The wound infection which caused the hemorrhage must be considered responsible for this death. Penicillin had been administered immediately after the first operation but despite this precaution infection developed.

Case 6. A 35-year-old soldier sustained a wound of the head and neck. The injury was followed by typical symptoms and signs of an arteriovenous communication between the internal carotid artery and the cavernous sinus. A bruit was audible to the patient and was particularly prominent when he was in bed at night. The left eye became prominent and its conjunctiva edematous and engorged. Six months after injury he was admitted to a vascular center in the Zone of Interior.

The left common carotid artery was ligated and as a result there was diminution of the bruit and decreased prominence of the left eye. Vascularity of the conjunctiva also became less. Since this operation did not eliminate the bruit completely, a second operation was performed at which the internal carotid artery was isolated and divided. The bruit was absent for about 2 weeks after this operation, then recurred at occasional intervals.

When the patient was on a furlough he had an episode of unconsciousness which was believed to be the result of a cerebral accident. When he returned to the hospital, the left eye had again become prominent, though not as prominent as when he was first seen, and the bruit was again audible. It was then decided that intracranial ligation of the affected artery must be attempted.

The internal carotid artery was excellently exposed by retraction of the left frontal lobe and was isolated at its point of exit from the cavernous sinus. Two tantalum clips were applied to it. Operation was carried out without incident and without undue loss of blood but the patient did not respond and died on the third postoperative day. At necropsy one of the tantalum clips was found on the carotid artery and the other on the posterior communicating branch.

Comment. Death in this case can be attributed to an insufficient arterial blood supply to the cerebral tissues.

MULTIPLE ANEURYSMS AND ARTERIOVENOUS FISTULAS

Since multiple vascular injuries were so frequent in World War II it was to be expected that certain casualties in whom sequelae from these injuries developed would sometimes present multiple lesions. Of the 814 aneurysms and arteriovenous fistulas observed at the vascular centers in the Zone of Interior, 46 occurred in 20 patients (Table 12).

TABLE 12. DISTRIBUTION OF MULTIPLE ANEURYSMS AND ARTERIOVENOUS FISTULAS AMONG 20 PATIENTS WITH 46 LESIONS

Arterial aneurysms	Arteriovenous fistulas	Number of lesions
	Anterior tibial, posterior tibial (2, including a branch), peroneal (branch)	4
	Ulnar	3
	Posterior tibial, carotid, femoral	3
	Posterior tibial	3
Posterior tibial	Posterior tibial, geniculate	3
	Profunda femoris	2
	Peroneal, anterior tibial	2
	Gastrocnemius, posterior tibial	2
	Femoral	2
	Femoral, brachial	2
	Femoral, carotid	2
	Profunda femoris, superior femoral	2
	Popliteal, posterior tibial	2
	Popliteal, posterior tibial	2
Brachial	Anterior tibial	2
Axillary	Posterior tibial	2
	External iliac, hypogastric	2
	Brachial, vertebral	2
Profunda femoris, femoral		2
Ulnar, radial		2
Total		46

Fifteen patients had 2 lesions each, 4 had 3 lesions, and 1 patient had 4 lesions. The 20 patients thus presented a total of 46 separate vascular sequelae of their combat-incurred injuries.

In 15 patients the multiple lesions were arteriovenous fistulas; in the 5 remaining the distribution was as follows: 2 had 2 aneurysms, 2 had an aneurysm and an arteriovenous fistula, and 1 patient had an aneurysm and 2 arteriovenous fistulas.

Because of its unusual character the case report of the patient with 4 arteriovenous fistulas is reported in detail.

Case 7. A 22-year-old sergeant was wounded on 16 August 1944 in Southern France by an exploding land mine. He received a compound comminuted fracture of the right fifth metatarsal bone in addition to multiple soft-tissue injuries of the back, thighs, legs, and feet. Bleeding was minimal. The wounds were dressed and casts applied to both legs.

The patient was transferred by ship to a station hospital in Italy. The cast was removed from the left leg on 1 September and from the right leg on 1 November. The patient was found to have some weakness of extension of the right foot, paralysis of the right toe extensors, hyperesthesia of the dorsal surface of the right toes, and hypesthesia in the distribution of the left saphenous nerve. He was evacuated to the Zone of Interior and on 31 October admitted to a general hospital.

Examination at the general hospital confirmed the neurologic findings in the right foot. The fracture was found to be healed. This examination also disclosed signs of the presence

of an arteriovenous fistula located anteriorly in the distal portion of the right leg. The patient was therefore transferred to a vascular center.

On 7 November 1944 when admitted to the vascular center at Mayo General Hospital he had few complaints. He stated that he had some weakness of extension of the right foot and toes, and occasionally a slight burning pain on the dorsal surface of this foot, but the hyperesthesia had disappeared. Along the left internal malleolus he still had some residual hypesthesia. He said the right foot was somewhat warmer than the left and that sweating was excessive in both feet. He denied having had color changes, venous difficulties, trophic changes, precordial distress, dyspnea, or cyanosis.

Physical examination revealed 150 wounds. All of them were well healed and most were very small. The majority were scattered over the legs, feet, and thighs. Roentgenologic examination of the extremities revealed numerous small metallic fragments scattered throughout the soft parts in these areas.

Neurologic findings were limited to a small area of hypesthesia along the left internal malleolus, loss of extensor power in the right toes, and some weakness of extension and eversion of the right foot.

All the toes of both feet became slightly cyanotic when in a dependent position. The peripheral arteries were neither tortuous nor thickened, the veins neither dilated nor thrombosed. Those in the right foot filled in 5 seconds, in the left after 15 seconds. The veins on the right side were somewhat better filled. Sweating of both feet was moderate. Slight pitting edema was present in the right foot and leg. There were no trophic changes.

About 10 cm. above the right internal malleolus, between the tibia and fibula anteriorly, an abnormal pulsation was present associated with a continuous thrill and a bruit audible down into the foot and up to the knee. Direct pressure over the anterior tibial vessels in this area obliterated the thrill, pulsation, and bruit, and produced a drop in the pulse rate from 72 to 67 beats per minute. When the arteriovenous fistula in the region of the right anterior tibial vessels was obliterated by direct pressure, a loud, continuous bruit was audible posteriorly in the calf about 20 cm. above the malleolar area. There was no thrill in this area and the bruit could be obliterated by rather broad pressure against the calf muscles proximal to the point of maximum bruit. About 20 cm. above the malleoli on the posterior medial aspect of the left leg a continuous thrill could be felt and a continuous bruit was heard. The bruit could not be obliterated by pressure in this area but ceased when the popliteal artery was compressed.

Blood pressure varied from 126 mm. of mercury systolic and 72 diastolic to 116 mm. of mercury systolic and 76 diastolic. It did not change when all the pulses in both legs were occluded, but the pulse rate dropped at this time from 84 to 68 beats per minute.

Skin temperatures of the toes on both feet were about equal. On one occasion, in a room at 22° C., the temperature of the toes on each foot varied from 22° to 23° C. and on another occasion from 32.5° to 35.5° Centigrade. When the reactive hyperemia test was carried out with the anterior tibial artery occluded, a good flush began in 25 seconds and was complete in 50 seconds.

It was concluded that the patient had 3 arteriovenous fistulas, 1 involving the right anterior tibial vessels and 2 probably involving the right and left posterior tibial vessels.

The patient was given a brief furlough at the conclusion of the examinations described. On his return he complained of some discomfort in both calves on walking and some swelling of both ankles. Examination at this time revealed moderate edema of both ankles. The circumference at this level was 2.5 cm. greater on the right than on the left side.

On 29 December 1944 the anterior tibial vessels of the right were explored and a double fistula found between the anterior tibial artery and two anterior tibial veins. The veins lay on either side of the artery. Each of these communications was about 4 mm. in diameter. The involved vessels were ligated proximally and distally, and the fistula excised. The post-operative course was smooth and the patient showed no evidence of vascular insufficiency at any time.

A second operation, this time on the left leg, was done 8 January 1945 through a posterolateral incision. The posterior tibial and the peroneal veins were found to be considerably dilated and to communicate through two channels. The posterior tibial vein itself communicated through a fistula about 5 mm. in diameter with the posterior tibial artery which also exhibited a saccular aneurysm on its wall opposite to the communication. This aneurysm was well organized and approximately 1 cm. in diameter. The lesions were excised and recovery was uneventful.

A third operation was carried out 12 February 1945, this time to locate the second aneurysm in the right leg. The posterior tibial artery and vein were exposed through a posteromedial incision in the calf. Both were found to be of normal size and appearance and no thrill could be palpated in this area. Palpation beneath the gastrocnemius, however, revealed a continuous thrill on the posterior aspect of the soleus muscle somewhat medial to the operative wound. The patient's muscles were so large and well developed that access to the involved area was not possible through the original incision and a second longitudinal incision was made posteriorly and directly over it. The gastrocnemius was divided in the direction of its fibers and the soleus exposed. Within the body of the latter muscle was found a small artery, about the diameter of a matchstick, which communicated with a vein about twice its size through a small saccular aneurysm 1 cm. in diameter. These vessels appeared to be muscular branches from the posterior tibial vessels. Artery and vein were ligated proximally and distally and the aneurysm and communicating vessels excised.

When these procedures had been completed the thrill and bruit originally present in this area were no longer present but a fairly loud and continuous bruit could be heard somewhat lateral and cephalad to the incision. Again the bulk of the muscles prevented access to the affected area through the original incision and a third longitudinal incision was made somewhat higher along the posterolateral aspect of the calf. When the fibers of the gastrocnemius muscle were separated and the soleus exposed, a small artery was found in the body of that muscle which communicated through a fistula with a vein dilated to the diameter of almost 1 centimeter. These vessels were thought to be muscular branches of the peroneal vessel. The vessels communicating with it were quadruply ligated and the fistula excised. Recovery was uneventful. A diagrammatic sketch of the fistulas found is shown in Figure 14.

When his convalescence from the third operation was completed, the patient was able to walk at a reasonably brisk pace for more than a mile with no resultant discomfort in the calves of his legs. He regained fairly complete power of extension of the right foot; likewise, function of all the extensors of the toes except that of the great toe.

The extremities no longer presented any edema and there was no substantial difference in their circumferences. Both feet were warm. Clinically the temperature appeared to be the same on both sides, but when a thermocouple was used it was found that the toes on the right foot tended to be somewhat warmer than those on the left. In a room in which the environmental temperature was 23° C., the temperature of the toes on the right foot varied from 32° to 33° C., and that of the toes on the left foot from 28° to 30° Centigrade. The pulsations of the posterior tibial artery were normal on the right side but absent on the left side. Both dorsalis pedis pulses were normal. Oscillometric readings at the ankles were 4.5 units on the right side and 3.5 units on the left at 90 mm. of mercury.

After operation the pulse was 72 beats per minute and the blood pressure 108 mm. of mercury systolic and 72 diastolic. The cardiac size was unchanged. The predicted frontal cardiac area for a man of this patient's height and weight was 124 square centimeters. The actual measurements on admittance and after each of the 3 operations were 112 square centimeters. Electrocardiograms taken before each of the operations showed no diagnostic deformity.

The patient was returned to duty after a neurosurgical consultant had agreed that the peroneal paralysis had so nearly disappeared that no operative procedure was indicated.

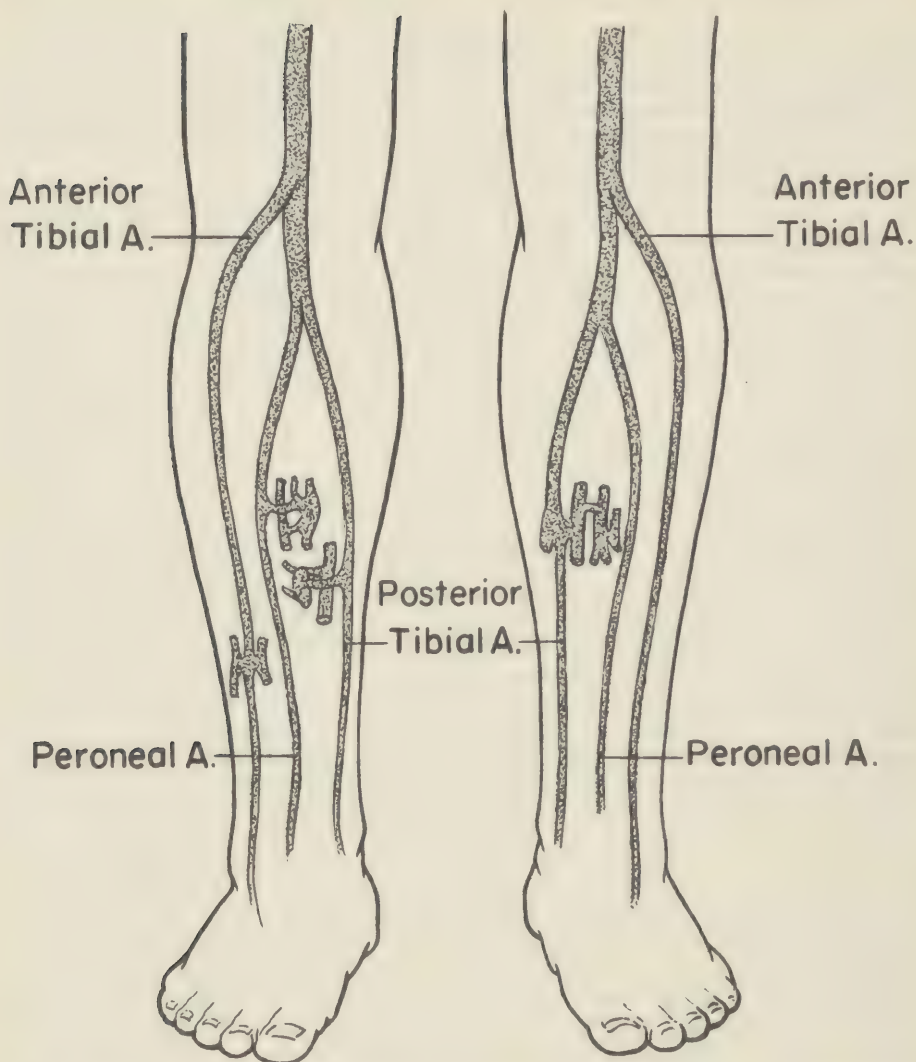


Figure 14. Diagrammatic showing of location and general appearance of the four arteriovenous fistulas present following injury by land mine. No effort has been made to draw the lesions to scale.

Comment. Careful palpation for thrill and auscultation for bruit should be an essential step of the final stages of operative procedures for the cure of arteriovenous fistulas. This case illustrates the wisdom of this precaution particularly in the battle casualty whose wounds are multiple and relatively small.

CHAPTER V

Arterial Aneurysms and Arteriovenous Fistulas Circulatory Effects of Arteriovenous Fistulas¹

Daniel C. Elkin, M. D.

LOCAL CIRCULATORY MANIFESTATIONS OF ARTERIOVENOUS FISTULAS

As in lesions observed in civilian practice, the local evidences of an arteriovenous fistula were similar regardless of the site of the lesion. The most common sign was the bruit, or murmur, which could be heard with a stethoscope in the region of the fistula. In contrast to the purely systolic sound of an arterial aneurysm, that produced by an arteriovenous fistula was a continuous murmur extending through both systole and diastole. Although in general the larger the fistula the louder the murmur, this was not always the case. At times small fistulas produced loud murmurs. These murmurs, like those arising from the heart, were transmitted a considerable distance from the site of origin. The chief cause of failure to hear the murmur was simply failure to listen for it.

When the murmur was of sufficient intensity, a thrill was generally felt. Again, although somewhat indicative of the size of the fistula, the intensity of the thrill did not offer completely reliable evidence of the size since it could be modified by the position of the fistula and the structures overlying it. The thrill was less well transmitted than the murmur, and was localized to an area near the lesion.

Some arteriovenous fistulas were associated with no external evidence of either arterial or venous dilatation. Occasionally, however, there was a pulsating mass of variable size in the affected area caused by aneurysmal dilatation of either the involved artery or vein, or by a false sac in the region of the fistula. Superficial veins near the fistula or distal to it were usually dilated and tortuous (Fig. 15). This dilatation disappeared soon after the artery was repaired. The pressure in the veins in the vicinity of the fistula was elevated but the systemic venous pressure was normal. Blood withdrawn from veins near the fistula always showed an abnormally high oxygen content.

In the region of the fistula itself the skin was warmer than normal but in the area distal to it there were sometimes signs of circulatory insufficiency ranging from local coolness and pallor to such severe manifestations as anemia or gangrene. Edema sometimes developed in the area distal to the lesion.

¹ The special studies reported in this chapter were made by James V. Warren, M. D., Emory University Hospital, Atlanta, Ga.



Figure 15. A. Plantar arteriovenous fistula. Note dilatation and tortuosity of superficial veins before operation. B. Same foot 2 weeks after excision of the fistula.

Skin temperature studies and oscillographic records confirmed these clinical observations (Chart 19). Oscillographic studies revealed increased pulsations at the site of the fistula which diminished gradually as they were measured proximally and distally.

When the vessels were exposed at operation the proximal artery and vein were usually dilated. The artery distal to the fistula was likely to be small, its size depending upon the amount of blood shunted away from it through the fistulous communication. The vein distal to the fistula was usually dilated because of the arterial blood shunted into it, though the enlargement was greater on the proximal side. All collateral branches in the region of the fistula, whether arterial or venous, were increased in size. Serial sections of the vessel walls did not usually reveal significant changes.

CARDIAC MANIFESTATIONS OF ARTERIOVENOUS FISTULAS

Patients with arteriovenous fistulas resulting from battle injuries usually presented no cardiac abnormalities upon physical examination. Alterations in size were sometimes observed, but only occasionally was the increase greatly in excess of normal standards. Whatever increase might be present could be detected only by the subsequent decrease in the transverse diameter of the heart as measured in teleoroentgenograms taken after operative eradication of the fistula (Fig. 16A and B). Only on relatively infrequent occasions was this increased size in excess of the normal standards; therefore it was noted only by the comparison of films made before and after the removal of the fistula. Occasionally, however, the heart became considerably enlarged. Since the alteration was reversible and disappeared promptly after removal of the fistula this enlargement was assumed to represent dilatation rather than true hypertrophy. The irreversible hypertrophy occasionally seen in patients

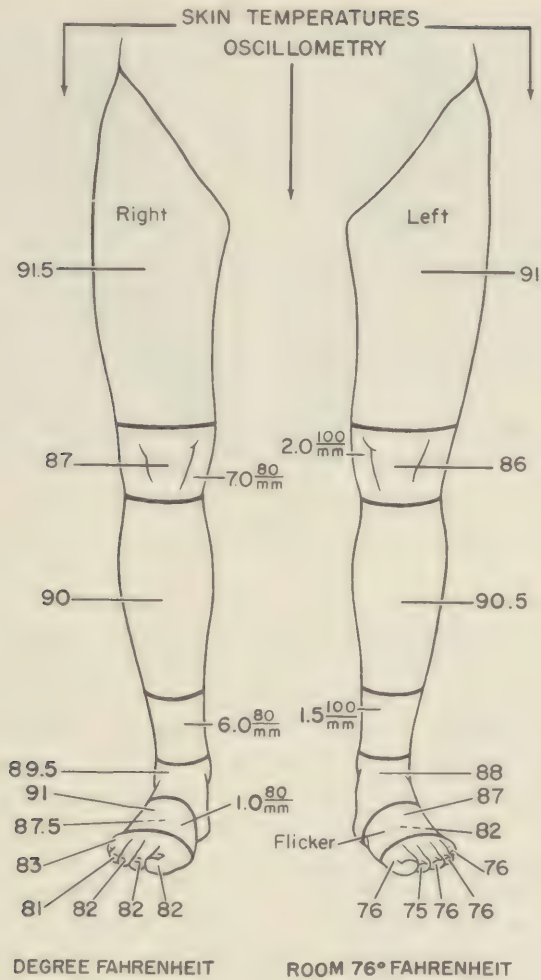


Chart 19. Oscillometric and skin temperature determinations in left plantar arteriovenous fistula. Note that oscillations and skin temperatures are reduced distal to the lesion.

with longstanding lesions was practically never observed in patients in military service since men were not inducted into the Army with such lesions.

It is generally recognized that in patients with arteriovenous fistulas congestive heart failure may develop, though the mechanism producing the cardiac decompensation is in dispute. It has been variously ascribed to the greatly increased demands on the heart and to the diminution of coronary blood flow secondary to the lowered mean arterial pressure.

Prior to World War II studies on the cardiac output in arteriovenous fistulas (a knowledge of which is essential in the elucidation of the altered circulatory dynamics in these patients) had been few in number and not

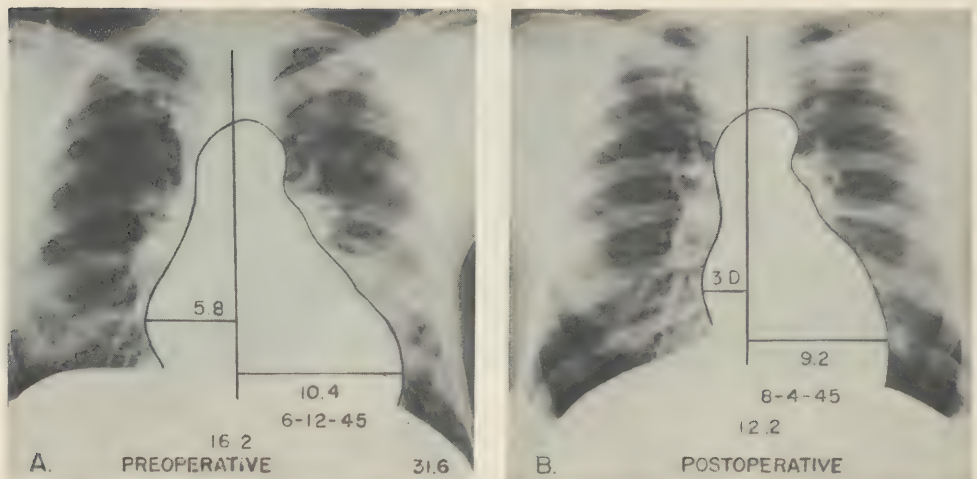


Figure 16. Serial teleoroentgenograms in femoral arteriovenous fistula. A. Preoperative view shows heart of increased size. B. Postoperative view shows decrease in cardiac size.

entirely consistent in results. Lewis and Drury,² whose studies were made with a glass cardiometer inclosing the heart, reported in 1923 that an increase in cardiac output was sometimes observed when an arteriovenous fistula was open and that an increased central venous pressure was observed in association with the elevated cardiac output. They therefore assumed that in human subjects the cardiac output was normal when the venous pressure was normal; no actual measurements were made. In 1924, Harrison, Dock, and Holman,³ who used the direct Fick technique, reported the elevation of cardiac output in animals with experimental arteriovenous fistulas; their observations were confirmed by a number of other observers. The few studies made on clinical subjects were much less conclusive, although in most instances the cardiac output was found to be increased. The possibility exists that the foreign gas methods often used in clinical studies were invalidated by the abnormal circulatory dynamics present in patients with arteriovenous fistulas.

Investigations conducted in peacetime were necessarily limited to experimental animals with artificially created fistulas and to clinical cases as they were encountered in individual experiences. During World War II the concentration of patients with these lesions at vascular centers in the Zone of Interior permitted studies which would be impossible except in time of war, and the investigations carried out throw some light, both positively and negatively, upon the alteration in circulatory dynamics caused by the presence of arteriovenous fistulas.

² Lewis, T., and Drury, A. N.: Observations relating to arteriovenous aneurism. *Heart* 10: 301-389, Oct 1923.

³ Harrison, T. R.; Dock, W., and Holman, E.: Experimental studies in arterio-venous fistulae; cardiac output. *Heart* 11: 337-341, Dec 1924.

Materials and Methods

At Ashford General Hospital the cardiac output was studied in 47 patients with arteriovenous fistulas by means of the low frequency, critically damped ballistocardiograph (Table 13). All but 1 of the 47 were males. The patients were presumably normal prior to their injuries and none had evidence of frank congestive heart failure. The interval between the injury which resulted in the arteriovenous fistula and the operative repair varied from 2 months to slightly over 2 years. Definite local signs of the fistula, including a thrill or murmur near its site, were present in all patients, and in all the fistula was demonstrated and eradicated successfully by surgical intervention. The postoperative course was without serious complications in all instances, and no patient presented evidence of recurrence of the lesion during the period of observation.

The ballistocardiograph, which was utilized to determine the cardiac output from the ballistic recoil of the body with each heart beat, is a table or bed so suspended on four steel strips or springs that movement only in the longitudi-

TABLE 13. PREOPERATIVE AND POSTOPERATIVE BALLISTOCARDIOGRAPHIC OBSERVATIONS IN 47 PATIENTS WITH ARTERIOVENOUS FISTULAS*

Location	Number of cases	Dura- tion of fistula	Time in relation to operation	Heart rate	Stroke volume	Cardiac index	Change in cardiac size	Change in blood volume
		Months	Days			Liters per minute per sq. meter	Cm.	Cc. per sq. meter
Carotid.....	5	5	6 before 14 after.....	70.0 73.0	116.3 80.3	4.5 3.7	-0.5	-440
Vertebral.....	1	8	1 before 18 after.....	81.0 78.0	114.0 93.8	4.5 3.7	-0.2	Unknown
Subclavian.....	3	3	19 before 14 after.....	71.0 71.0	114.0 80.5	4.0 2.8	+1.2	-155
Axillary.....	3	11	13 before 14 after.....	65.2 78.0	145.1 104.8	4.9 4.5	Unknown	-200
Brachial.....	4	5	5 before 14 after.....	74.0 66.0	122.0 94.5	4.3 3.9	-0.2	+40
Iliac.....	3	7	15 before 20 after.....	84.0 72.0	115.8 80.0	7.1 3.2	-0.6	-453
Femoral.....	12	5	8 before 16 after.....	82.0 73.0	115.7 94.9	6.0 3.9	-1.2	-304
Popliteal.....	5	10	9 before 21 after.....	66.5 65.6	134.6 103.9	4.8 3.6	-0.3	-210
Tibial.....	11	8	6 before 23 after.....	67.0 70.0	107.4 94.0	4.0 3.5	-0.2	-123

*Figures in columns 3 through 9 are averages.

nal direction is possible. The length of the springs is adjustable and the inherent frequency of the bed can therefore be kept constant in spite of variations in the weights of patients. When the bed is displaced it returns to its original resting position without overshoot because it is critically damped. Movements of the bed are recorded photographically, by means of a light beam and mirror, with a camera similar to that used in an electrocardiograph. The output of the heart was calculated in the studies at Ashford General Hospital from the measurement of several features of the ballistocardiographic tracing and the determination of the patient's blood pressure (Chart 20). The ballistocardiographic measurements were checked against comparative studies by the direct Fick technique. The observations were recorded in terms of the cardiac index, that is, the output of the heart in liters per minute per square meter of body surface, in order to facilitate comparisons between individuals of various sizes.

All determinations were made 3 hours or more after the previous meal and after the patient had relaxed on the ballistocardiographic table for 15 minutes or more. Arterial pressure was obtained by the auscultatory method with an ordinary mercury manometer. The transverse cardiac diameter as measured from teleoroentgenograms was used as an index of changes in the size of the heart.

Although several studies had previously been made to determine the correlation between the ballistocardiographic method and the Fick catheter

TEMPORARY OCCLUSION OF ARTERIOVENOUS FISTULA

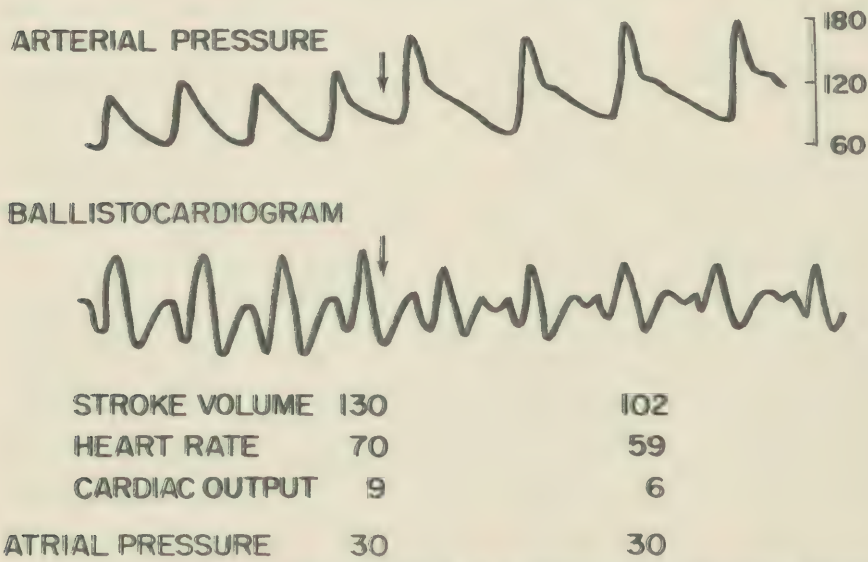


Chart 20. Effects of temporary occlusion of arteriovenous fistula on arterial pressure, stroke volume, heart rate, cardiac output, and atrial pressure.

method of measuring the cardiac output, additional studies were made as a part of this investigation to establish the validity of the ballistocardiographic method under the conditions of the investigation. The control studies were made on 3 patients with arteriovenous fistulas and on 3 others with large areas of reactive hyperemia. Reactive hyperemia was produced by applying blood pressure cuffs around the upper parts of both legs and then inflating them above arterial pressure for 20 minutes. The state of reactive hyperemia which ensued when the cuffs were released was for all practical purposes a temporary arteriovenous fistula. With the release of the cuffs the cardiac output in each case rapidly rose to about twice the normal level.

Results

The control studies described established the validity of the ballistocardiograph as a means of measuring the output of the heart. Excellent correlation was obtained.

The blood pressure showed little variation from the preoperative to the postoperative period. In the cases in which a change occurred, the tendency was toward diminution of the pulse pressure after operation chiefly because of an elevation of the diastolic pressure.

When the normal resting cardiac output, that is the postoperative value, was compared with the preoperative cardiac output, the latter was found to range from 21 percent below, to 127 percent above the former (Chart 21). (For correct interpretation of these results it is necessary to bear in mind that variations of as much as 25 percent above or below the value selected as the resting cardiac output can be expected in normal subjects when repeated measurements are made at different times.)

The postoperative alteration in cardiac output was obviously the result of a change in stroke volume rather than of a change in pulse rate. When the fistula was intact the basal pulse rate was above 85 in only 7 of the 47 patients, the vessels involved in these 7 patients were the femoral vessels in 4 patients, the iliacs in 2, and the subclavian in 1. The cardiac output in this group of patients before operation ranged from 32 to 127 percent (average 82 percent) above the postoperative level (Chart 22).

Comment

It is fortunate that the ballistocardiographic method of studying the cardiac output is apparently accurate since it possesses several important advantages over other methods now available: (1) From the patient's standpoint this is the simplest of all methods since he merely lies on the table completely relaxed and does not have to endure the psychologically disturbing effects of the introduction of needles or the use of a rebreathing apparatus. (2) Repeated determinations can easily be made on the same subject. (3) Extremely rapid changes in cardiac output, which cannot be observed by other methods, can be studied by this method.

EFFECT OF A-V FISTULA ON CARDIAC OUTPUT

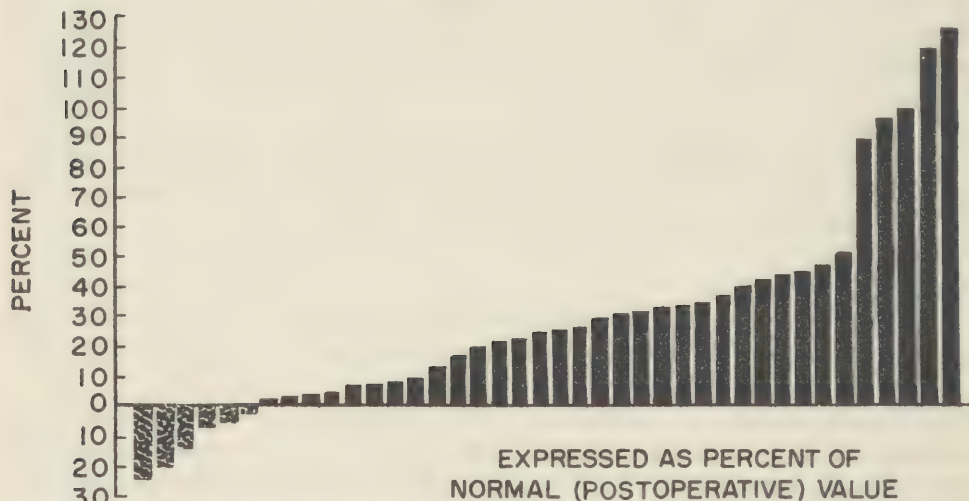


Chart 21. Effects (in percentages of normal values) of arteriovenous fistula on cardiac output. The shaded bars represent the variation of increase and the black bars the variation of decrease. A change of less than 25 percent in cardiac output is considered within the range of normal variation. Note that only 40 of the 47 patients studied are depicted in the chart inasmuch as readings were not obtained on 7.

FEMORAL ARTERIOVENOUS FISTULA

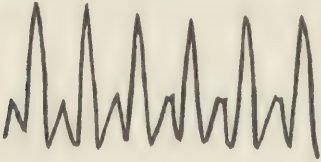
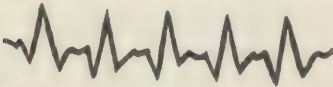
	<u>PULSE RATE</u>	<u>STROKE VOLUME</u>	<u>CARDIAC INDEX</u>
BEFORE OPERATION			
	81	204	9.0
AFTER OPERATION			
	73	114	4.5

Chart 22. Ballistocardiographic observations before and after excision of femoral arteriovenous fistula.

The person-to-person variability in cardiac output is large and in this series the postoperative cardiac index varied considerably from patient to patient but the range was similar to that found in comparable normal subjects studied by the catheter method by Stead, Warren, Merrill, and Brannon.⁴ If necessary, the investigation at Ashford General Hospital could have been carried out by using the average normal value obtained by this study, but all the patients in the series returned to a normal state after operation without evidence of residual abnormality in the circulation, and there seemed full justification for utilizing individual postoperative values as the basis for estimating the load placed on the heart by the fistula before operation.

Since a variation of 25 percent above and below the postoperative cardiac index could be expected in any group of subjects, a change after operation within this range could not be attributed to the effect of the fistula on the circulation. In 22 of the 47 patients, approximately 47 percent, the postoperative alteration was within this range. In the other 25 patients the cardiac output when the fistula was open was more than 25 percent greater than the output after it had been closed at operation, the altered values ranging from 25 to 127 percent. In other words, slightly more than half of the 47 patients with arteriovenous fistulas studied by the ballistocardiographic method had a significantly elevated cardiac output before operation as measured under basal conditions.

It was difficult to estimate the functional size of the fistula from either clinical or pathologic evidence. The size of the vessel involved and the intensity of the thrill or the murmur were not entirely reliable in predicting the increase in the cardiac output, though in general, clinical evidence of a large fistula or of the presence of a fistula located in a large vessel was associated with the greatest increase in cardiac output. An analysis of the 47 cases showed that while all of the patients with the most appreciable increase in cardiac output had fistulas involving relatively large vessels, the relationship appeared to be no more specific. A fistula involving the femoral vessels might be associated with a large increase in the cardiac output, but did not necessarily cause it. On the other hand a fistula fed by a small vessel, because of the limited arterial inflow, produced at the most a small increase in the cardiac output. The increase in the cardiac output is perhaps, as Starr's studies⁵ indicate, the best index of the load placed on the circulation by an arteriovenous fistula.

When an attempt was made to correlate the duration of the fistula with the increase in cardiac output it was found that in general the greatest increases in cardiac output occurred in association with fistulas of relatively short duration, and vice versa. A reasonable explanation of this observation is that larger fistulas were promptly diagnosed (and the patients sent immediately to the vascular centers), while small fistulas were frequently overlooked for long periods of time.

⁴ Stead, E. A., Jr.; Warren, J. V.; Merrill, A. J., and Brannon, E. S.: Cardiac output in male subjects as measured by the technique of right atrial catheterization; normal values with observations on the effect of anxiety and tilting. *J. Clin. Investigation* 24: 326-331, May 1945.

⁵ Starr, I.: Clinical studies; with the ballistocardiograph in congestive failure, on digitals action, on changes in ballistic form, and certain acute experiments. *Am. J. M. Sc.* 202: 469-485, Oct 1941.

Cardiac enlargement, as demonstrated by an increased transverse cardiac diameter in teleoroentgenograms, is recognized as a frequent accompaniment of arteriovenous fistula. The increase is reversible and the heart returns to its normal size after the fistula is corrected. An attempt to correlate the change in the transverse diameter of the heart following operation on the patients in this series with the degree of increase in cardiac output resulted in a correlation coefficient of 0.12, which is not significant. This lack of correlation suggests comparison with the observations made in arterial hypertension in which the amount of cardiac enlargement cannot be directly correlated with either the degree or the duration of the increased arterial pressure. Given 2 patients with the same degree of hypertension, 1 may have marked cardiac enlargement and the other no enlargement at all. Such was the case in instances of cardiac enlargement associated with arteriovenous fistula in this series.

From these studies it may therefore be concluded that many, though by no means all, patients with arteriovenous fistulas have distinct elevations of the cardiac output as a result of the lesion, with a return to values apparently normal after correction of the fistula. These observations are in accord with previous observations.

Why the increased cardiac output occurs is a question of considerable interest. Most textbooks stress the importance of the filling pressure of the ventricles, that is, the pressure in the atria and the great veins, but this is not an adequate explanation: The studies by Starr and his associates,⁶ corroborated in this series, show that in patients with large areas of reactive hyperemia there may be a decided change in cardiac output without any change at all in right atrial pressure.

With this change eliminated as the explanation of the increased cardiac output in association with arteriovenous fistulas, changes in the arterial tree offer a possible explanation. When the fistula is open there is a definite reduction in peripheral resistance. Ballistocardiographic studies show that when the fistula is compressed and then released, changes in stroke volume and heart rate are almost instantaneous. The evidence indicated that the alteration in cardiac output is predominantly the result of change in stroke volume rather than pulse rate and is related to change in the arterial tree rather than to an increase in filling pressure presented to the right side of the heart.

An increase in cardiac output also occurs in clinical conditions in which the circulatory dynamics are altered as they are altered in arteriovenous fistulas. In patent ductus arteriosus, for instance, which is actually an arteriovenous fistula between the aorta and the pulmonary artery, such an increase was reported by Eppinger, Burwell, and Gross.⁷ During the later months of preg-

⁶ Starr, I.; Rawson, A. J.; Schroeder, H. A., and Joseph, N. R.: Studies on the estimation of the cardiac output in man, and of abnormalities in cardiac function, from the heart's recoil and the blood's impacts; the ballistocardiogram. *Am. J. Physiol.* 127: 1-28, Aug 1939.

⁷ Eppinger, E. C.; Burwell, C. S., and Gross, R. E.: Effects of the patent ductus arteriosus on circulation. *J. Clin. Investigation* 20: 127-143, Mar 1941.

nancy the cardiac output is almost always elevated, and Burwell ⁸ has pointed out that in many ways the placenta behaves like a modified arteriovenous fistula.

The studies carried out at Ashford General Hospital furnish no direct evidence concerning cardiac failure in patients with arteriovenous fistulas. It seems possible, however, that in this condition just as in patent ductus arteriosus, severe anemia, and thyrotoxicosis, failure occurs when the cardiac output is far above normal. In arteriovenous fistula one would not necessarily expect a low cardiac output to indicate circulatory inadequacy, though cardiac failure would not necessarily develop in patients with the highest cardiac outputs. The resistance of the cardiovascular system to stress varies widely from person to person and the amount of overwork which causes failure in one subject would not necessarily cause it in another.

The explanation is probably along the lines suggested by Starr and Jonas ⁹ for cardiac failure in thyrotoxicosis: It occurs in patients in whom the heart is not able to increase its output to meet increased demands, which means that a normal cardiac output in a patient with extreme hyperthyroidism may be taken to indicate the possibility of cardiac failure. Similarly, cardiac failure might be expected to develop in patients with arteriovenous fistulas in whom the cardiac output does not increase to compensate for the loss of effective output by way of the fistula.

The combination of a normal cardiac output and a large fistula might therefore be more indicative of cardiac insufficiency than a large cardiac output per se. If this reasoning is correct, it furnishes an additional explanation of the inability in this investigation to correlate cardiac enlargement or elevated blood volume directly with the increase in cardiac output.

THE BLOOD VOLUME IN ARTERIOVENOUS FISTULAS

Holman,¹⁰ in 1924, seems to have been the first to report an increase in blood volume in animals in which arteriovenous fistulas had been produced, with a return to normal level following the removal of these lesions. In his method the dye brilliant vital red was used to determine the blood volume. Four minutes after the dye was injected a sample of blood was drawn. The five animals in which he had produced particularly large arteriovenous communications all showed an increased blood volume, and in general the increase appeared to be related to the size of the fistula. Similar blood volume studies were reported later in clinical cases of arteriovenous fistulas, the increased blood volume in most instances returning to normal after correction of the lesions.¹¹

⁸ Burwell, C. S.: Placenta as a modified arteriovenous fistula considered in relation to the circulatory adjustments to pregnancy. *Am. J. M. Sc.* 195: 1-7, Jan 1938.

⁹ Starr, I., and Jonas, L.: Supernormal circulation in resting subjects (hyperkinemia), with a study of the relation of kinemic abnormalities to the basal metabolic rate. *Arch. Int. Med.* 71: 1-22, Jan 1943.

¹⁰ Holman, E.: Experimental studies in arteriovenous fistulas; blood volume variation (pt 1). *Arch. Surg.* 9: 822-836, Nov 1924.

¹¹ (1) Holman, Emile: *Arteriovenous Aneurysm. Abnormal Communication Between Arterial and Venous Circulations*. New York, The Macmillan Company, 1937.

(2) Holman, E.: Clinical and experimental observations on arteriovenous fistulae. *Ann. Surg.* 112: 840-875, Nov 1940.

In Rowntree and Brown's blood volume studies¹² on 7 patients with arteriovenous fistulas, 3 of which were congenital, the average value for the group was slightly above normal but only 1 patient showed a distinct elevation. Pemberton and Saint¹³ reported finding a somewhat elevated value in a single patient with a congenital arteriovenous communication. In view of their own observation on 3 patients, studied before and after operation, Reid and McGuire¹⁴ expressed some doubt concerning changes in the blood volume in arteriovenous fistulas. In the first case there was no essential change. In the second there was a decrease of 1,000 cc. after operation, but 9 months later the value was the same as before operation. The same authors reported a slight increase in the blood volume in 2 experimental animals with arteriovenous fistulas. Ellis and Weiss,¹⁵ who used Evans blue dye T-1824 to study a single patient before operation, found the blood volume within normal limits. Kennedy and Burwell¹⁶ found a greatly elevated blood volume before operation in a patient with multiple arteriovenous communications; the fistulas recurred in this case and there was considerable fluctuation in the postoperative results.

The methods used in the early studies of the blood volume in arteriovenous fistulas are open to many theoretical and practical objections. The later observations mentioned, which are not open to these objections, are limited in number. For these reasons, advantage was taken of the concentration of patients with arteriovenous fistulas in the vascular centers of the Zone of Interior to attempt more conclusive studies on the blood volume in the presence of these lesions.

Materials and Methods

The blood volume was studied at Ashford General Hospital in 41 patients with arteriovenous fistulas by means of the blue dye T-1824 (Table 14). All the lesions followed trauma. The patients, 1 of whom was a woman, were all young adults and all apparently healthy prior to injury. At the time of the investigation none had complicating injuries or illnesses which might have altered the blood volume.

Blood vessels in all parts of the body were involved. Every patient presented the physical signs characteristic of arteriovenous fistulas and in no instance was there any evidence of frank cardiac decompensation. The interval between wounding and operation varied from 2 months to a little over 2 years.

¹² Rowntree, Leonard G., and Brown, George E.: *The Volume of the Blood and Plasma in Health and Disease*. Philadelphia, W. B. Saunders Company, 1929.

¹³ Pemberton, J. de J., and Saint, J. H.: Congenital arteriovenous communications. *Surg., Gynec. & Obst.* 46: 470-483, Apr 1928.

¹⁴ Reid, M. R., and McGuire, J.: Arteriovenous aneurysms. *Ann. Surg.* 108: 643-693, Oct 1938.

¹⁵ Ellis, L. B., and Weiss, S.: Local and systemic effects of arteriovenous fistula on the circulation in man. *Am. Heart J.* 5: 635-647, Jun 1930.

¹⁶ Kennedy, J. A., and Burwell, C. S.: Measurements of the circulation in a patient with multiple arteriovenous connections. *Am. Heart J.* 28: 133-148, Aug 1944.

TABLE 14. PREOPERATIVE AND POSTOPERATIVE BLOOD VOLUME STUDIES IN 41 PATIENTS WITH ARTERIOVENOUS FISTULAS*

Location	Number of cases	Duration of fistula	Time in relation to operation	Plasma volume	Hematocrit	Total blood volume	Deviation from normal blood volume	Total plasma protein	Cardiac size
		Months	Days	Cc.	Cc. cells in 100 cc.	Cc.	Cc. per sq. meter	Gm. %	Cm.
Carotid.....	1	3. 5	1 before.... 21 after....	2650. 0 2420. 0	48. 2 44. 8	5100. 0 4385. 0	- 440 -----	6. 7 6. 1	- 1. 5 -----
Subclavian....	4	3. 5	7 before.... 12 after....	2848. 8 2932. 5	49. 1 46. 1	5540. 0 5387. 5	- 168 -----	6. 0 6. 4	+ 0. 5 -----
Axillary.....	5	8. 1	12 before.... 20 after....	2990. 0 2806. 0	47. 7 46. 8	5700. 0 4947. 0	- 123 -----	6. 3 6. 4	- 5. 6 -----
Brachial.....	3	3. 5	6 before.... 10 after....	2620. 0 2970. 0	47. 8 49. 4	5053. 3 5220. 0	+ 90 -----	6. 4 6. 5	- 0. 0 -----
Iliac.....	4	6. 0	14 before.... 14 after....	3146. 3 2667. 5	44. 3 46. 4	5616. 9 4957. 5	- 365 -----	6. 9 6. 3	- 0. 6 -----
Femoral.....	13	6. 1	6 before.... 14 after....	2972. 5 2618. 5	47. 6 49. 4	5645. 6 5169. 2	- 284 -----	6. 2 6. 4	- 1. 2 -----
Popliteal....	5	6. 8	7 before.... 15 after....	2827. 0 2856. 0	49. 2 47. 7	5584. 0 5476. 0	- 76 -----	6. 4 6. 8	- 0. 2 -----
Tibial.....	6	8. 7	3 before.... 20 after....	2735. 0 2661. 7	45. 6 45. 0	5068. 3 4865. 8	- 117 -----	6. 2 6. 5	- 0. 4 -----

*Figures in columns 3 through 10 are averages.

In every case the fistula was successfully excised, with no complications postoperatively. Thiopental sodium anesthesia or continuous spinal analgesia was used.

Determinations of the blood volume were made under basal conditions, at least 12 hours after the last meal and before patients had risen in the morning. With the exception of the determinations made on the third postoperative day, all preoperative and postoperative studies were made on patients who were ambulatory.

The plasma volume was measured with blue dye T-1824, as recommended by Gregersen, Gibson, and Stead.¹⁷ Blood samples were drawn from the ante-cubital veins. The syringes used were dry and in order to avoid hemoconcentration, tourniquets were not used. Following withdrawal of the dye-free sample, 3 cc. of the dye (0.1-percent solution) were injected from a calibrated

¹⁷ Gregersen, M. I.; Gibson, J. J., and Stead, E. A.: Plasma volume determination with dyes; errors in colorimetry; use of the blue dye T-1824. *Am. J. Physiol.* 113: 54-55, Sep 1935.

syringe which was then rinsed three times with blood. Care was taken to prevent extravascular loss of the dye. If any loss occurred, a note was made of it. Exactly 10 minutes after the dye had been injected, a sample of blood was obtained with the proper precautions against hemolysis and hemoconcentration. In some cases an indwelling needle was left in place and serial samples were obtained to determine the rate of disappearance of the dye.

The blood samples were placed in small tubes where they were covered with mineral oil and allowed to clot and retract before they were gently centrifuged. Any sample which showed evidence of lipemia or hemolysis was discarded.

The concentration of the dye T-1824 was determined by measuring the light absorption of the dye-containing serum sample in relation to the dye-free sample at a wave length of 620 millimicrons with a Coleman Junior spectrophotometer or with a Nickerson decade photometer.¹⁸ The apparatus had previously been calibrated with known amounts of dye in serum.

The plasma volume was calculated from the single 10-minute point as suggested by Gregersen and Rawson,¹⁹ or from the dye concentration value obtained from extrapolation of the disappearance curve plotted on a semilogarithmic scale. The total blood volume was determined from the plasma volume and the hematocrit reading. To facilitate comparisons between patients of different sizes, the blood volume per square meter of body surface was also calculated.

When the dye-free blood specimen was withdrawn, sufficient blood was also obtained for hematocrit readings, and determinations of hemoglobin and total protein. Heparin was used as the anticoagulant in the hematocrit tubes. The hemoglobin concentration was determined by measuring the optical density of a dilute alkaline solution of blood. The total protein value was determined by the density method of Barbour and Hamilton.²⁰

Many of the patients in whom blood volume studies were made underwent additional studies including determination of the cardiac output by means of the ballistocardiograph and estimations of the size of the heart by measurement of the transverse cardiac diameter on a teleoroentgenogram.

Results

In the 41 patients studied, the blood volume per square meter of body surface ranged before operation from 2,400 cc. to 4,030 cubic centimeters. Ten days or more after operation the values ranged from 2,330 cc. to 3,380 cc., the alterations varying from a decrease of 1,060 cc. to an increase of 190 cubic centimeters. In 23 cases, approximately 56 percent of the series, the change was less than 200 cubic centimeters. In 18 patients, 44 percent of the series,

¹⁸ Nickerson, J. L.: Portable decade photometer for determination of blood volume with the dye T-1824. *Rev. Scient. Instruments* 15: 69-72, Mar 1944.

¹⁹ Gregersen, M. I., and Rawson, R. A.: Disappearance of T-1824 and structurally related dyes from the blood stream. *Am. J. Physiol.* 138: 698-707, Apr 1943.

²⁰ Barbour, H. G., and Hamilton, W. F.: Blood specific gravity; its significance and a new method for its determination. *Am. J. Physiol.* 69: 654-661, Aug 1924.

there was a postoperative decrease in the blood volume which ranged from 200 to 1,060 cc. per square meter. In no patient was the rise following operation greater than 200 cc. (Chart 23). These data were confirmed in most instances by serial observations.

Plasma volume fluctuated as did the total blood volume. Hematocrit readings varied only slightly but more often than not showed a tendency to fall slightly after operation. Calculated red blood cell volume underwent similar changes. Changes in hemoglobin values and total protein concentration were not significant.

Comment

Technical Methods. The blue dye T-1824 had been widely used for the determination of the plasma volume. In this series two methods were originally employed, the semilogarithmic plotting of disappearance of the dye, as recommended by Gregersen and Rawson,²¹ and the examination of the single dyed specimen obtained 10 minutes after injection of the dye as recommended by Gregersen²² for certain situations. The latter method, simpler to perform, proved as reliable as an extrapolated value for dye concentration obtained from the disappearance curve of the dye. Gregersen's results with the two methods were obtained in normal subjects and in subjects in shock. In the cases in this series in which both methods were used there was no evidence that the disappearance rate of the dye was affected by the presence of the arteriovenous fistula, and the plasma volume obtained by both methods was substantially the same. After the reliability of both methods had been established by comparative studies, Gregersen's 10-minute method was used almost exclusively because its simplicity permitted serial determinations of the plasma volume of a large number of patients who were available for study for a limited time only. No patient in this series had frank congestive heart failure; however, there is a possibility that the prolonged mixing time of the dye in this type of case might invalidate the 10-minute method.

The calculation of total blood volume from the hematocrit reading and plasma volume has been criticized adversely by some observers on two counts: (1) the imperfection of the peripheral venous hematocrit reading as evidence of the proportion of cells in the blood throughout the body, and (2) the failure of the hematocrit reading to indicate the true cell-plasma ratio because of plasma trapped among the cells. These determinations proved useful in this series, however, because comparative observations were made in the same persons with minimal hematocrit changes.

In this study total blood volume was determined instead of plasma volume because the body appears to maintain it at a constant level at the expense of the cell-plasma ratio and hence it is a more stable value. Plasma volume ap-

²¹ See footnote 10, p. 194.

²² Gregersen, M. I.: Practical method for determination of blood volume with the dye T-1824. *J. Lab. & Clin. Med.* 29: 1266-1286, Dec 1944.

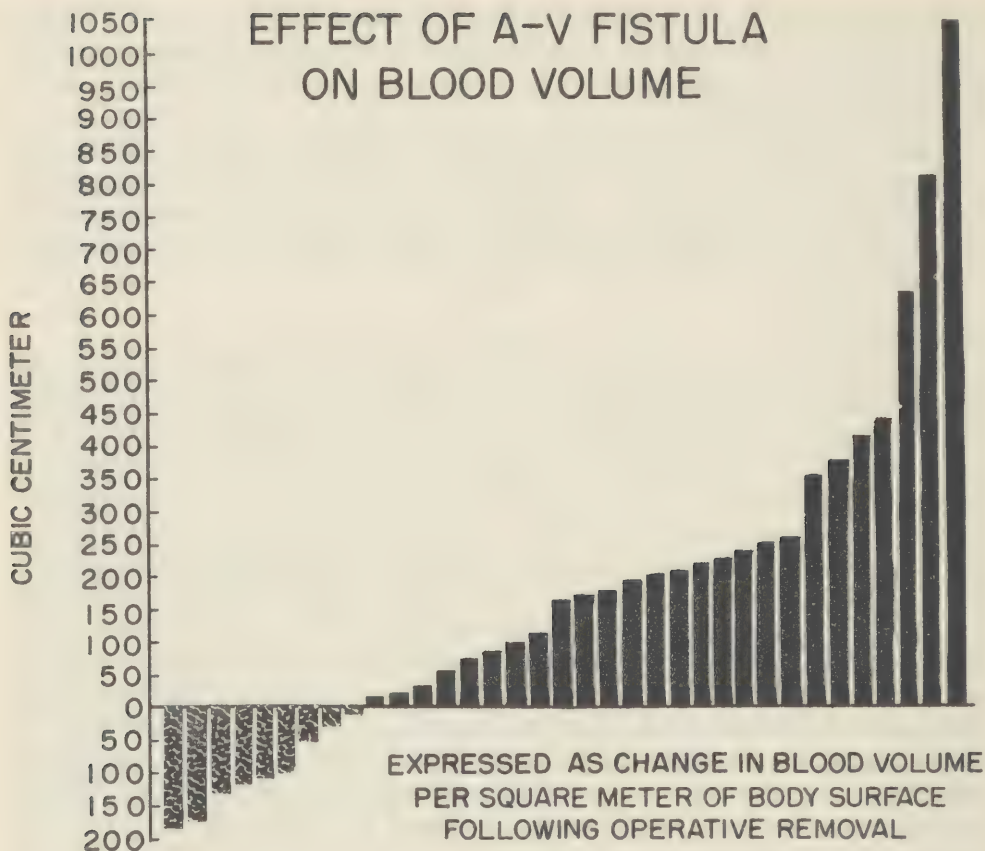


Chart 23. Effects on blood volume (expressed as changes per square meter of body surface) of excision of arteriovenous fistula. The shaded bars represent the variation of increase and the black bars the variation of decrease. A change of 200 cc. in blood volume is considered within the range of normal variations. Note that only 35 of the 41 patients are depicted in the chart inasmuch as readings were not obtained for 6.

parently varies rapidly to compensate for changes in red cell volume because the body can mobilize fluid and protein with relative rapidity. Studies on the effect of simple hemorrhage by Ebert, Stead, and Gibson²³ indicate that changes in plasma volume occur with a slow readjustment of the red cell volume and hematocrit reading to the normal value. Similar changes might be seen soon after an operation in which blood loss and dehydration have occurred. For these reasons plasma volume is subject to much more fluctuation than is total blood volume, and information concerning it was of less value for the purposes of this study than evidence of changes in total blood volume.

²³ Ebert, R. V.; Stead, E. A., Jr., and Gibson, J. G., Jr.: Response of normal subjects to acute blood loss, with special reference to the mechanism of restoration of blood volume. Arch. Int. Med. 68: 578-590, Sep 1941.

Although some of the postoperative measurements calculated on these patients were made relatively soon after operation, they were delayed long enough to escape any immediate effects of the procedure, for example, blood loss and dehydration. Only observations made 10 days or more after operation were used in the calculation of normal values; by this time almost all the patients were ambulatory. The average blood volume per square meter of body surface was approximately 2,800 cc., which is within the same range as the values reported for normal male subjects by Gibson and Evans.²⁴

Results. The majority (23) of the 41 patients in this series showed a difference of less than 200 cc. between the preoperative and postoperative blood volumes per square meter of body surface. Such a change, which amounted to only about 7 percent of the normal value, might have been expected as a result of technical errors in the determinations, i. e., factors introduced by the operation and bed rest without regard to the presence of the arteriovenous fistula and its eradication. On the other hand, although in no instance was the postoperative increase in blood volume greater than 200 cc., 18 patients, almost 44 percent, showed a postoperative decrease greater than 200 cubic centimeters. In several instances serial observations showed the decline to be in progress by the third day after operation and to be apparently complete by the 10th day.

Observations made on these patients were in agreement with previous observations to the effect that blood volume may be significantly elevated in patients with arteriovenous fistulas. This is not, however, an inevitable reaction, since elevations were observed in only 18 of the 41 patients studied. Previous studies had supplied no satisfactory explanation of the alteration, and an attempt was therefore made to relate it to other alterations in the circulation observed in patients with arteriovenous fistulas at the vascular center of Ashford General Hospital.

The possibility that the increase in blood volume might be related to the size of the fistula was investigated. In this series 3 or 4 patients with the most extreme elevations in blood volume had fistulas which involved the iliac vessels. It was difficult, however, to establish this explanation because the exact size of the fistula could rarely be determined. Clinical evidence, such as the size of the vessels involved and the intensity of associated thrills and murmurs, supplied some data concerning the magnitude of the shunt of blood, but was obviously not accurate. Actual measurement of the fistulous opening at time of operation did not prove successful because of vascular spasm, and measurement of the specimen after removal was unsatisfactory for the same reason and because tissue fixation resulted in shrinkage.

As was pointed out previously in this chapter, the resting level of cardiac output is above normal in many patients with arteriovenous fistulas. Since it is possible that the elevation of the cardiac output above normal may be

²⁴ Gibson, J. G., and Evans, W. A., Jr.: Clinical studies of the blood volume; relation of plasma and total blood volume to venous pressure, blood velocity rate, physical measurements, age and sex in 90 normal humans. *J. Clin. Investigation* 16: 317-328, May 1937.

proportional to the size of the fistula, an attempt was made to correlate this increase with the increase in the blood volume. In order to avoid the difficulties inherent in the range in basal cardiac output in the series, blood volume change was plotted against percentage deviation from normal in cardiac output. In other words, if cardiac output before operation was twice the basal value determined after operation, an increase in cardiac output of 100 percent was plotted. The coefficient thus obtained, 0.26, did not indicate any significant correlation.

In spite of the negative results just reported, it was still thought possible that the size of the fistula might be at least one of several factors responsible for the increased blood volume observed in some patients with arteriovenous fistulas. It has been well established by roentgenologic methods that in this lesion the heart may increase in size with the development of the fistula but return to normal size after the fistula is removed. In view of the evidence already existing that the size of the heart is related to the magnitude of the blood volume, an attempt was made to correlate these measurements in the 29 patients in the series who had preoperative and postoperative teleoroentgenograms, which in some instances were serial. Changes in the blood volume were plotted against changes in the transverse diameter of the heart as measured on the teleoroentgenogram. The correlation coefficient thus obtained, 0.36, indicated that the degree of correlation between these values was not significant.

It cannot be said that these results were surprising. Earlier studies by Weens, Brannon, and Warren²⁵ had shown that in normal subjects a rapid increase in blood volume of about 1,000 cc. fails to produce any distinct change in the heart size. It is true that Holman²⁶ was able to produce changes in the size of the heart in dogs when he increased or decreased the blood volume, but these experimental changes were of much greater magnitude than those observed clinically in arteriovenous fistulas. A change of 500 cc. in dogs would be roughly equivalent to a change of 4,000 cc. in a human subject. In neither of the studies just mentioned was the increase in blood volume accompanied by an increase in extracellular fluid volume, which might alter the situation considerably. It seems likely that other factors than cardiac size, such as the increased demand placed on the heart, may play a major role in the increase in blood volume in arteriovenous fistulas.

An attempt to relate the increase in the blood volume to the duration of the arteriovenous fistula proved unsuccessful because few patients in this series had large fistulas of long duration. The lesions of longest duration, as already mentioned, were usually of small size, for which reason many of them had been overlooked originally by both patients and medical attendants.

The results of the study of arteriovenous fistulas at Ashford General Hospital thus produced no explanation for the elevation sometimes observed in blood volumes with the onset of the lesion or for the return to normal levels after its eradication. This is scarcely surprising, since the basic factors con-

²⁵ Weens, H. S.; Brannon, E. S., and Warren, J. V.: Unpublished data.

²⁶ See footnote 10, p. 191.

trolling the size of the blood volume in normal subjects are still imperfectly understood.

Holman²⁷ advanced the opinion that the increase in blood volume merely compensates for the loss of blood through the fistula. His apparently interchangeable use of the terms blood volume and volume of blood flow somewhat confuses the explanation.

Reid and McGuire's suggestion²⁸ was that the increase in blood volume seen in patients with arteriovenous fistulas represents merely the nonspecific increase in blood volume seen in patients with congestive heart failure of any type and is not the specific result of the presence of the arteriovenous fistula. Although none of the patients studied at Ashford General Hospital developed the complete clinical picture of cardiac failure, it seems possible that there might have been a similar mechanism at work in the cases in which an increase in blood volume was observed. Warren and Stead²⁹ pointed out that in patients with chronic congestive heart failure the increase in blood volume, as well as certain other abnormalities in fluid dynamics, could be explained by a deficient output of the heart rather than, as it is usually explained, by increased venous pressure. If this explanation is correct, it may be that the mechanism of the increase in blood volume in patients with arteriovenous fistulas is similar: In cardiac failure the circulation would be inadequate because of the inability of the heart to pump blood. In arteriovenous fistula the blood flow would be inadequate because much of the cardiac output is shunted through the fistula.

Previously in this chapter attention was called to the similarity between cardiac output in arteriovenous fistulas and conditions such as patent ductus arteriosus and pregnancy, i. e., increase of cardiac output through alteration of circulatory dynamics. Although the mechanism by which the increase in blood volume observed in arteriovenous fistulas is attained is not fully understood, the basic explanation may be an increase in the production of blood. When some large venous channels are engorged with blood, as they are when this lesion is present, the amount of blood remaining in the rest of the vascular bed would be less than normal unless increased production of blood were stimulated.

THE EFFECT ON HEART RATE, STROKE VOLUME, AND CARDIAC OUTPUT OF TEMPORARY OCCLUSION OF ARTERIOVENOUS FISTULAS

Slowing of the heart rate, the most commonly recognized result of temporary occlusion of an arteriovenous fistula, was first described by Nicoladoni³⁰

²⁷ See footnote 11 (1), p. 191.

²⁸ See footnote 14, p. 192.

²⁹ Warren, J. V., and Stead, E. A.: Fluid dynamics in chronic congestive heart failure; interpretation of the mechanisms producing the edema, increased plasma volume and elevated venous pressure in certain patients with prolonged congestive failure. *Arch. Int. Med.* 73: 138-147, Feb 1944.

³⁰ Nicoladoni, C.: Phlebarteriectasie der rechten oberen Extremität. *Arch. f. klin. Chir.* 18: 252-274, 1875.

in 1875. In 1890 Branham³¹ also described it without knowledge of the previous description, and it is now usually referred to as Branham's sign. Further observations on this sign, and on the effect on the stroke volume and cardiac output of temporary occlusion of arteriovenous fistulas, were made on a group of patients with these lesions at the vascular center of Ashford General Hospital (Table 15).

TABLE 15. PREOPERATIVE AND POSTOPERATIVE STUDIES OF EFFECTS OF TEMPORARY OCCLUSION IN 25 PATIENTS WITH ARTERIOVENOUS FISTULAS*

Location	Number of cases	Duration of fistula	Time in relation to operation	Fistula occluded	Heart rate	Stroke volume	Arterial pressure	Cardiac index
		Months	Days			Cc.	Mm. Hg.	Liters per minute per sq. meter
Brachial-----	2	4	4 before-----	No--	70. 4	126. 5	128/80	4. 8
			5 before-----	Yes--	54. 0	115. 5	125/80	3. 4
			9 after-----	-----	68. 8	105. 9	122/67	4. 0
Femoral-----	7	4	6 before-----	No--	77. 4	132. 8	119/91	5. 7
			4 before-----	Yes--	61. 4	104. 9	118/74	3. 6
			15 after-----	-----	69. 8	93. 0	115/74	3. 5
Popliteal-----	5	10	9 before-----	No--	65. 9	135. 4	118/58	4. 9
			11 before-----	Yes--	55. 8	102. 5	117/82	3. 7
			17 after-----	-----	65. 6	103. 8	115/49	4. 8
Tibial-----	11	8	6 before-----	No--	67. 8	107. 5	122/10	4. 0
			7 before-----	Yes--	63. 4	91. 9	124/79	3. 2
			23 after-----	-----	68. 4	95. 5	114/66	3. 6

*Figures in columns 3 through 9 are averages.

Materials and Methods

The investigation was carried out on 25 patients with arteriovenous fistulas of traumatic origin, none of whom presented clinical evidence of cardiac decompensation or of any complicating disease which might be expected to alter the response of the vascular system. They formed part of the group upon whom studies of the cardiac output had been made but were limited to those with lesions of the extremities.

The patient under investigation was placed in the critically damped ballistocardiograph described earlier in this chapter and a blood pressure cuff bound about the affected extremity in such a way that when it was deflated there was no interference with the venous blood flow. The fistula was occluded by rapidly raising the pressure in the cuff to 200 mm. of mercury from a pressure bottle system. To familiarize the patient with the method and to be certain that no discomfort was connected with it, the procedure was carried out

³¹ Branham, H. H.: Aneurismal varix of the femoral artery and vein following a gunshot wound. *Internat. J. Surg.* 3: 250-251, Nov 1890.

several times before the ballistic records were begun. Ballistic tracings and arterial blood pressure determinations by the auscultatory method were obtained with the fistula open and with it occluded. At least 2 sets of observations were made on each patient. In 5 patients the observations were repeated after 2 mg. of atropine sulfate had been injected intravenously and enough time had elapsed for it to exert its maximum effect (Table 16). In all patients after operative removal of the fistula another ballistocardiographic record was made.

Results

Ballistocardiographic tracings showed that when the arteriovenous fistula was suddenly occluded, 17 of the 25 patients showed a decrease in the heart rate ranging from 4 to 32 beats per minute. In the other 8 patients a decrease also occurred but it was less than 4 beats.

In 19 patients the stroke volume of the heart decreased more than 10 cc. when the fistula was suddenly occluded. The effect of occlusion on the cardiac index (the cardiac output in liters per minute per square meter of body surface) varied from no change at all to a decrease of 3.6 liters. In 22 of the 25 patients the decrease was 0.5 liter or more. Under the conditions of the study, 0.5 liter probably represented the minimal detectable change.

Changes in arterial pressure following occlusion of the fistula were seldom marked. The diastolic pressure increased almost constantly; the increase in the systolic pressure was less frequent.

In all 5 patients in whom additional studies were made after injections of atropine, an increased pulse rate was observed. In some instances this was accompanied by an increase in the cardiac index over the basal level. When the fistula was occluded, although the change in the pulse rate did not exceed 4 beats per minute in any case, stroke volume was altered in every instance. Decline in the cardiac index was from 1.0 to 2.2 liters per minute per square meter; that in cardiac output was from 1.8 to 4.2 liters (Table 16).

Comment

The ballistocardiograph was not altogether ideal for the purposes of this study because it prevented the use of manual compression for the occlusion of the arteriovenous fistula. Since this compression would have interfered with the movements of the ballistic bed, a blood pressure cuff was used which meant that not only the fistula itself was occluded but all the circulation of the extremity distal to the cuff as well. Observations on normal subjects, however, and on the normal extremities of patients with arteriovenous fistulas elsewhere in the body, showed practically no change in the cardiac output or pulse rate when it was employed. For comparative purposes, the Matas compressor, which occludes only the major vessel entering the fistula, was tested in 1 patient. Response of heart rate and cardiac output was the same by both methods.

TABLE 16. PREOPERATIVE STUDIES OF EFFECTS OF TEMPORARY OCCLUSION WITH AND WITHOUT ATROPINIZATION IN 5 PATIENTS WITH ARTERIOVENOUS FISTULAS ¹

Location	Fistula occluded	Heart rate	Stroke volume	Arterial pressure	Cardiac output	Cardiac index
			Cc.	Mm. Hg	Liters per minute	Liters per minute per sq. meter
Femoral-----	No	83	124	110/60	10.3	5.8
	Yes	61	107	115/70	6.5	3.7
	No ²	100	123	125/85	12.3	7.0
	Yes ²	104	83	145/95	8.6	4.9
Femoral-----	No	76	158	120/55	12.0	6.5
	Yes	44	139	125/70	6.1	3.3
	No ²	93	105	130/85	9.7	5.3
	Yes ²	94	84	150/90	7.9	4.3
Popliteal-----	No	83	140	115/60	11.6	6.0
	Yes	62	110	115/70	6.8	3.5
	No ²	123	127	135/90	15.6	8.0
	Yes ²	119	102	140/100	12.1	6.2
Popliteal-----	No	62	93	110/60	5.8	3.6
	Yes	59	70	115/75	4.2	2.6
	No ²	102	86	120/65	8.8	5.5
	Yes ²	102	62	130/85	6.4	4.0
Tibial-----	No	71	132	120/60	9.4	5.0
	Yes	57	120	120/80	6.9	3.6
	No ²	98	100	140/90	9.8	5.2
	Yes ²	96	59	160/100	5.6	3.0

¹In each case the dose of atropine was 2 mg. intravenously.²After atropinization.

The results of this investigation further confirmed the well-accepted fact that closure of an arteriovenous fistula is usually accompanied by slowing of the heart rate, though the specific stimulus which results in the bradycardic response is not clearly understood, just as the mechanism producing the change is still to be elucidated. The speed of the reaction suggests that a nervous reflex may be involved. It has been suggested that the vascular bed in and around the fistula may take on a function similar to that assumed in carotid sinus or aortic depressor areas in that local pressure changes are reflected by reflex changes in cardiac function. This does not seem likely. Observations by Gerlach and Harke,³² which were confirmed by observations at the vascular center of Ashford General Hospital, show that Branham's sign can be produced when a patient is under high spinal analgesia and when the area of the fistula

³² Gerlach, F., and Harke, W.: Compression of arteriovenous aneurysms. *Klin. Wchnschr.* 3: 980-981, May 1924.

is presumably devoid of functional nervous connections, though it is not certain that functional denervation is complete.

Lewis and Drury³³ found it possible to block the slowing of the heart rate produced by occlusion of the fistula by a preliminary administration of atropine and the same result was observed in the 5 patients in this series in which this method was used. Ellis and Weiss,³⁴ and Kramer and Kahn,³⁵ made the same observations. Rieder's negative results³⁶ can probably be explained by the use of inadequate dosages. The effect of atropine has been interpreted as evidence that the pulse-slowng response is mediated not only by a nervous mechanism in general but by the vagus nerve in particular.

According to the results of this investigation, occlusion of the fistula also produces a striking decrease in the stroke output of the heart. This decrease, together with the decrease in the heart rate, results in a reduction of the cardiac output. The stroke volume reduction, however, is independent of the change in the heart rate, and atropine which can abolish the change in the heart rate does not affect the reduction in the stroke volume (Chart 24).

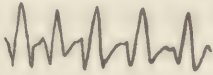
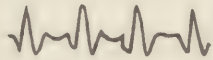
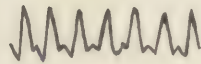
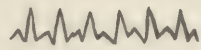
	BALLISTOCARDIOGRAM	PULSE RATE	STROKE VOLUME	CARDIAC INDEX
FISTULA OPEN		86	140	6.2
FISTULA OCCLUDED		62	110	3.5
AFTER ATROPINE FISTULA OPEN		120	151	9.3
AFTER ATROPINE FISTULA OCCLUDED		120	94	5.8

Chart 24. Ballistocardiographic studies in popliteal arteriovenous fistula before and after intravenous administration of 2 mg. of atropine sulfate. Note that after administration of the drug the pulse rate rises but is not slowed when the fistula is occluded, although the stroke volume and cardiac index both decrease.

Changes in the stroke volume occur very promptly, significant alterations appearing within the first three heart beats after the fistula is occluded. On theoretical grounds three possible mechanisms might be responsible: (1) a change in the emptying of the heart, (2) a variation in the degree of diastolic relaxation of the ventricles, and (3) a change in the pressure gradient producing filling

³³ See footnote 2, p. 184.
³⁴ See footnote 15, p. 192.
³⁵ Kramer, M., and Kahn, J. H.: Unpublished data.
³⁶ Rieder, W.: Heart impairment due to arteriovenous aneurysm. Arch. f. klin. Chir. 139: 597-606, 1926.

of the ventricles. If either of the first two processes is responsible, the mechanism must be under nervous control because of the rapidity with which changes in the stroke volume appear. It is not likely that the vagus forms part of the reflex pathway since atropine, which suppresses the vagal control of the heart rate, does not affect the stroke volume. If a change in the pressure gradient causing filling of the ventricles is responsible for the change in the stroke volume, it also occurs rapidly. Studies of catheterization of the right side of the heart carried out by Nickerson, Warren, and Brannon³⁷ indicate that no significant change occurs in the mean right atrial pressure when the fistula is closed, though there are large changes in the stroke volume. The conclusion that there is no change in the pressure gradient causing filling of the heart is not necessarily correct, however, since a pressure gradient cannot be determined by measuring the pressure at a single point in a system.

Changes in cardiac output and stroke volume similar to those described in these 25 patients with arteriovenous fistulas occurred in normal subjects upon the production of large areas of reactive hyperemia. When blood pressure cuffs were placed about the upper thigh and inflated to 200 mm. of mercury pressure, little change in the heart rate and cardiac output was noted. When the pressure was continued for 20 minutes and observations were made as it was released, increases in heart rate and cardiac output were almost double the prepressure levels. These changes, as in the patients with arteriovenous fistulas, occurred without significant alteration in the atrial pressure.

In general, the output of the heart following temporary occlusion of an arteriovenous fistula was almost the same as the output under similar conditions several weeks after operative removal of the fistula. Since the cardiac output is a highly variable function changing markedly under the influence of even the emotional content of thought, it is difficult to say whether the lack of exact coincidence in the values represented a real difference in output, dependent upon the length of time the fistula was closed, or merely represented a variation in the conditions under which the values were obtained.

It was not possible in these studies to confirm Holman's observation³⁸ that proximity of the fistula to the heart is important in the cardiac output. The size of the fistula and of the vessels feeding it seemed more important than its position in determining the amount of blood flowing through it. Fistulas close to the heart were associated with both large and small increases in cardiac output.

SUMMARY AND CONCLUSIONS

The concentration of casualties with vascular injuries in vascular centers in general hospitals in the Zone of Interior in World War II presented an unparalleled opportunity for the study of certain phases of arteriovenous

³⁷ Nickerson, J. L.; Warren, J. V., and Brannon, E. S.: Cardiac output in man; studies with the low frequency, critically-damped ballistocardiograph and the method of right atrial catheterization. *J. Clin. Investigation* 26: 1-10, Jan 1947.

³⁸ See footnote 11 (1), p. 191.

fistulas. This chapter is the record of the studies carried out at the vascular center at the Ashford General Hospital.

The investigation included studies of the local and systemic effects of arteriovenous fistulas on the circulation and of their effect on the size of the heart, the cardiac output, and the blood volume.

In many of the subjects both the cardiac output and blood volume were elevated above normal level and the size of the heart was somewhat increased. After operative eradication of the fistula there was a practically uniform return of all three to normal. None of the patients under investigation developed frank congestive heart failure.

Studies carried out after temporary occlusion of arteriovenous fistulas included slowing of the pulse rate (Branham's sign), which is apparently mediated by the vagus nerve, and almost immediate lowering of the cardiac output and stroke volume of the heart, the latter reaction apparently being a nervous reflex related to the sudden change in resistance against which the heart must pump. The pulse pressure decreases on occlusion of the fistula because of the rise in diastolic pressure, thus returning the character of the pulse to normal.

In spite of the information secured by these various studies, a rational and more nearly complete explanation of the genesis of the effects of an arteriovenous fistula on the circulation must await an extension of basic knowledge concerning the circulatory system.

CHAPTER VI

Arterial Aneurysms and Arteriovenous Fistulas Alterations in the Cardiac Size in Arteriovenous Fistulas

Harris B. Shumacker, Jr., M. D.

Although numerous instances of cardiac enlargement associated with the presence of arteriovenous fistulas were recorded prior to the outbreak of World War II, these reports, for the most part, concerned only individual cases or small groups of cases. No series large enough to supply statistical data were on record and such conclusions as had been arrived at concerning this phenomenon were based, therefore, on clinical impressions. The experience in World War II altered this situation. At the vascular center of Mayo General Hospital detailed studies of the heart size before and after operative removal of the traumatic arteriovenous fistula were carried out on a large number of patients with this type of lesion. These studies have made possible certain conclusions based on factual data.

MATERIALS AND METHODS

The studies reported in this chapter were carried out on 185 soldiers with traumatic arteriovenous fistulas which in all but a few instances followed combat-incurred injuries. Only 1 patient was a woman and most of the group were young adults.

Clinical Manifestations. This series does not include any patient in whom organic heart disease was known to exist. While a number of patients complained of dyspnea on exertion, palpitation, or a distressing pounding of the heart especially when recumbent, many others who presented roentgenologic evidence of a considerable increase in cardiac frontal area complained of no symptoms which were referable to the heart.

Among the 185 soldiers there were only 2 instances of frank cardiac failure. In 1 the episode occurred before the first roentgenologic examination was made. This patient had 2 traumatic fistulas, 1 involving the external iliac vessels and 1 involving the hypogastric vessel. The severe dyspnea, orthopnea, and edema originally present after his injury disappeared after resection of the iliac fistula in a hospital overseas. Although his heart was still enlarged he was relatively asymptomatic between the first operation and the second, when excision of the hypogastric fistula brought about a further decrease in the cardiac frontal area.

The second patient with frank cardiac failure, whose cardiac frontal area had progressively increased in size, became extremely orthopneic when he experienced a small pulmonary infarction and a *Streptococcus viridans* septicemia as the result of infection of the fistula (see Chapter IV). After the fistula had been excised he was relieved of all symptoms and the heart returned to normal size.

Methods. Teleoroentgenograms were made in all 185 patients in the series, usually both before and after operation. The predicted and actual frontal areas of the cardiac silhouette were calculated according to the method of Ungerleider and Gubner,¹ calculations of the predicted values being made according to the height and weight of the patients on their admission to the vascular center.

Before operation, whenever the location of the fistula permitted it, several determinations of the blood pressure and pulse, with and without occlusion of the fistula, were made. The precise findings at operation were recorded in each patient; in most instances these observations included actual measurements or a careful estimation of the size of the fistula.

ANALYSIS OF DATA

Regional Distribution. An analysis of the 185 patients with arteriovenous fistulas from the standpoint of location of the lesion (Table 17), showed that in 131 these involved vessels of the pelvis and lower extremity, while in 54, vessels of the head, neck, and upper extremity were affected. (There were 53 patients with fistulas of the femoral artery—the highest number for any single vessel.)

Age Distribution. The age range in this series was 19 to 46 years; average age was 24.5 years. The age range varied somewhat in the different anatomic groups (Table 17), but average ages for patients with lesions of the pelvis and lower extremity (24 years) and for lesions of the head, neck, and upper extremity (25.7 years) were not widely different. The lowest average age, 22.4, occurred in patients with lesions of the femoral artery and the highest, 27.7 years, in those with lesions in the miscellaneous group of vessels in the upper part of the body not segregated into special categories.

Duration of Fistula. The time interval between injury and operation in these 185 patients varied from 1.0 to 30.0 months and averaged 5.4 months (Table 18). However, there was little difference in the average duration of the fistula in most of the regional categories. The highest average duration, 9.2 months, was in the category which included the profunda femoris, hypogastric, obturator, and superior gluteal arteries and can probably be explained by the small number of cases (9) in this group. The data on the time interval between injury and the final preoperative roentgenogram and between operation and the final postoperative roentgenogram are given in Table 18 and require no special comments.

¹ Ungerleider, H. E., and Gubner, R.: Evaluation of heart size measurements. *Am. Heart J.* 24: 494-510, Oct 1942.

TABLE 17.—LOCATION OF LESION AND AGE DISTRIBUTION

Location of fistula	Number of patients	Age range	Average age
		<i>Years</i>	<i>Years</i>
Pelvis and lower extremity	131	19-45	24. 0
Femoral	53	19-34	22. 4
Popliteal	36	19-45	25. 8
Profunda femoris, hypogastric, obturator, superior gluteal	9	20-27	22. 9
Vessels of leg	33	19-34	25. 0
Head, neck, and upper extremity	54	20-46	25. 7
Carotid, vertebral	14	20-46	27. 0
Subclavian, axillary	17	20-41	22. 7
Brachial	9	21-35	26. 0
Other vessels of head, neck, and upper extremity*	14	20-34	27. 7
Total	185	19-46	24. 5

*This group includes fistulas of the ulnar, radial, posterior circumflex humeral, thoracoacromial, subscapular, transverse cervical, occipital, and lingual vessels.

TABLE 18. INTERVAL IN MONTHS BETWEEN INJURY AND PREOPERATIVE ROENTGENOGRAM, BETWEEN INJURY AND OPERATION, AND BETWEEN OPERATION AND POSTOPERATIVE ROENTGENOGRAM

Location of fistula	Number of patients	Interval between (in months)					
		Injury and last preoperative roentgenogram		Injury and operation		Operation and final postoperative roentgenogram	
		Range	Average	Range	Average	Range	Average
Pelvis and lower extremity	131	0. 8-26. 0	4. 8	1. 3-30. 0	5. 5	0. 1-8. 0	1. 6
Femoral	53	1. 2-19. 0	4. 4	1. 3-20. 0	4. 7	0. 2-8. 0	2. 0
Popliteal	36	0. 8-10. 5	4. 6	1. 8-10. 6	5. 7	0. 1-7. 0	1. 4
Profunda femoris, hypogastric, obturator, superior gluteal	9	3. 0-26. 0	8. 6	4. 0-30. 0	9. 2	0. 1-2. 0	1. 0
Vessels of leg	33	1. 2-10. 0	4. 7	1. 6-14. 0	5. 6	0. 2-7. 5	1. 3
Head, neck, and upper extremity	54	0. 7-15. 0	4. 5	1. 0-15. 0	5. 3	0. 1-6. 3	1. 5
Carotid, vertebral	14	0. 7-10. 0	4. 7	1. 0-10. 0	4. 5	0. 2-1. 7	0. 7
Subclavian, axillary	17	1. 5- 8. 0	4. 5	1. 5- 9. 0	4. 9	0. 4-5. 5	2. 2
Brachial	9	1. 7- 4. 5	3. 0	2. 0- 6. 0	4. 4	1. 0-3. 0	2. 1
Other vessels of head, neck, and upper extremity*	14	3. 4-15. 0	5. 6	4. 5-15. 0	7. 2	0. 1-6. 3	1. 4
Total	185	0. 7-26. 0	4. 7	1. 0-30. 0	5. 4	0. 1-8. 0	1. 6

*This group includes fistulas of the ulnar, radial, posterior circumflex humeral, thoracoacromial, subscapular, transverse cervical, occipital, and lingual vessels.

MEASUREMENTS OF THE CARDIAC FRONTAL AREA

Preoperative measurements of the cardiac frontal area were made in 153 of the 185 patients in this series, postoperative measurements were made in 161, and both preoperative and postoperative measurements in 132 (Tables 19, 20, and 21).

TABLE 19. PROPORTIONATE DISTRIBUTION OF PREOPERATIVE MEASUREMENTS OF THE CARDIAC FRONTAL AREA

Location of fistula	Number of patients	Cardiac frontal area*						
		<85	85-105	106+	111+	116+	121+	126+
Pelvis and lower extremity-----	108	1.9	36.1	62.0	50.0	37.0	27.7	15.7
Femoral-----	39	0.0	15.5	84.5	74.3	53.8	48.7	28.2
Popliteal-----	33	3.0	30.5	66.5	51.4	36.3	27.2	15.1
Profunda femoris, hypogastric, obturator, superior gluteal-----	6	0.0	83.3	16.7	0.0	0.0	0.0	0.0
Vessels of leg-----	30	3.3	59.8	36.9	26.9	23.3	6.6	3.3
Head, neck, and upper extremity-----	45	6.7	55.5	37.8	29.2	18.1	11.1	2.2
Carotid, vertebral-----	11	9.1	45.4	45.5	27.3	0.0	0.0	0.0
Subclavian, axillary-----	13	0.0	76.9	23.1	15.4	0.0	0.0	0.0
Brachial-----	9	11.1	33.4	55.5	44.4	44.4	22.2	11.1
Other vessels of head, neck, and upper extremity-----	12	8.3	58.4	33.3	33.3	33.3	25.0	0.0
Total-----	153	3.3	41.8	54.9	43.8	31.4	23.9	11.8

*Measurements of cardiac frontal area are expressed in percentages of predicted area.

Control Measurements. It proved impossible because of the heavy workload in this vascular center to take measurements of the cardiac frontal area in a comparable group of soldiers without arteriovenous fistulas but with otherwise similar physical and nutritional states. In the true sense of the term, therefore, this series provides no data of a control group. An analysis was made, however, of the final postoperative cardiac measurements in 119 patients whose fistulas had been removed by operation and whose preoperative measurements had not exceeded 115 percent of normal (Chart 25). Excluded from this group were patients in whom there was a great increase in heart size before operation, in whom it seemed likely that hypertrophy as well as dilatation of the heart might have occurred, and in whom some degree of cardiac enlargement might have persisted after operative removal of the fistula.

TABLE 20. PROPORTIONATE DISTRIBUTION OF POSTOPERATIVE MEASUREMENTS OF CARDIAC FRONTAL AREA

Location of fistula	Number of patients	Cardiac frontal area*					
		<85	85-105	106+	111+	116+	121+
Pelvis and lower extremity-----	118	6.8	65.2	28.0	18.6	11.0	5.9
Femoral-----	51	3.9	64.7	31.4	21.6	15.7	7.8
Popliteal-----	31	9.7	58.0	32.3	25.8	9.7	9.7
Profunda femoris, hypogastric, obturator, superior gluteal-----	8	25.0	63.5	11.5	0.0	0.0	0.0
Vessels of leg-----	28	3.6	75.0	21.4	10.8	7.2	0.0
Head, neck, and upper extremity-----	43	13.3	63.4	23.3	4.6	0.0	0.0
Carotid, vertebral-----	11	18.2	72.7	9.1	0.0	0.0	0.0
Subclavian, axillary-----	15	26.7	46.6	26.7	6.7	0.0	0.0
Brachial-----	4	0.0	75.0	25.0	0.0	0.0	0.0
Other vessels of head, neck, and upper extremity-----	13	0.0	69.2	30.8	7.7	0.0	0.0
Total-----	161	8.7	64.6	26.7	14.9	8.1	4.3

*Measurements of cardiac frontal area are expressed in percentages of predicted area.

TABLE 21. PROPORTIONATE DISTRIBUTION OF POSTOPERATIVE ALTERATIONS IN CARDIAC FRONTAL AREA

Location of fistula	Number of patients	Decrease*				No essential change*	Increase*
		6+	11+	16+	21+	±5	6+
Pelvis and lower extremity-----	99	63.7	44.4	28.3	10.1	32.3	4.0
Femoral-----	38	79.0	52.6	44.7	13.2	18.4	2.6
Popliteal-----	29	65.5	55.2	31.0	17.2	27.6	6.9
Profunda femoris, hypogastric, obturator, superior gluteal-----	7	42.9	42.9	14.3	0.0	57.1	0.0
Vessels of leg-----	25	44.0	20.0	4.0	0.0	52.0	4.0
Head, neck, and upper extremity-----	33	42.4	30.3	18.2	9.1	54.6	3.0
Carotid, vertebral-----	9	44.4	22.2	22.2	11.1	55.6	0.0
Subclavian, axillary-----	10	40.0	40.0	30.0	20.0	60.0	0.0
Brachial-----	4	25.0	25.0	0.0	0.0	50.0	25.0
Other vessels of head, neck, and upper extremity-----	10	50.0	30.0	10.0	0.0	50.0	0.0
Total-----	132	58.3	40.8	25.8	9.8	37.9	3.8

*Alterations are expressed in percentage of change from preoperative values.

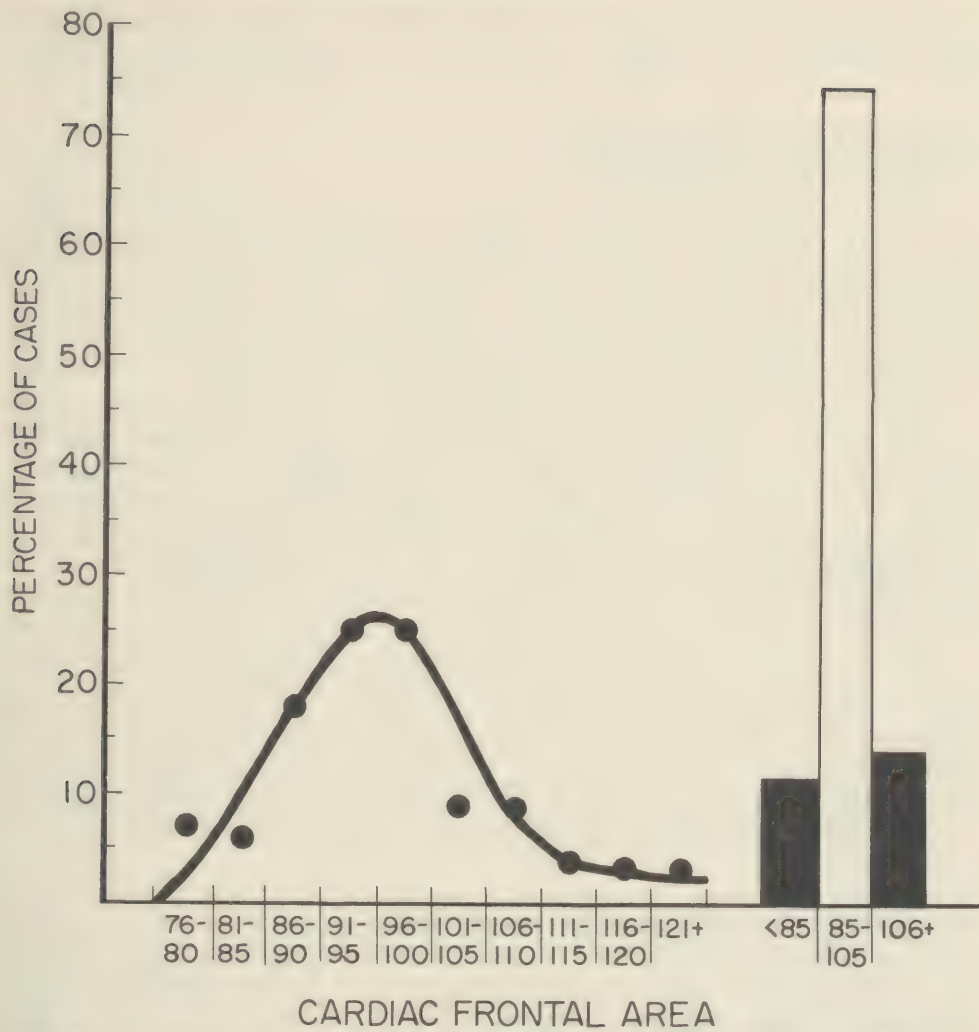


Chart 25. Distribution of measurements of cardiac frontal area (in terms of predicted area) after operative cure of arteriovenous fistulas in 119 patients in whom the preoperative measurements had not exceeded 115 percent of the predicted. Note that the majority of the values fall within the 85-105 percent range.

In these 119 patients (Chart 25) the postoperative measurements of the cardiac frontal area tended to center around 95 percent of the calculated predicted values. Almost three-fourths of the patients (74.8 percent) had measurements ranging from 86 to 105 percent of predicted values. In 11.8 percent actual measurements were less than 85 percent of predicted values, and in 13.4 percent they were higher than 105 percent of these values. When 100 percent of the predicted value was used as the presumed normal figure, a smaller number of patients (69.8 percent) fell into the ± 10 percent range,

and the measurements in the remaining patients were less evenly distributed. Only 5.0 percent of the patients then had values in excess of 110 percent while 25.2 percent had values lower than 90 percent of the predicted values.

Comparative Preoperative-Postoperative Measurements of the Cardiac Frontal Area

Preoperative measurements were made on 153 patients (Table 19, Charts 26 and 27). Of these, 54.9 percent had measurements of the cardiac frontal area in excess of 105 percent of the predicted values; in 11.8 percent they exceeded 125 percent of these values. Forty-one and eight-tenths percent had measurements between 85 and 105 percent of the predicted size, while 3.3 percent showed measurements less than 85 percent of this size.

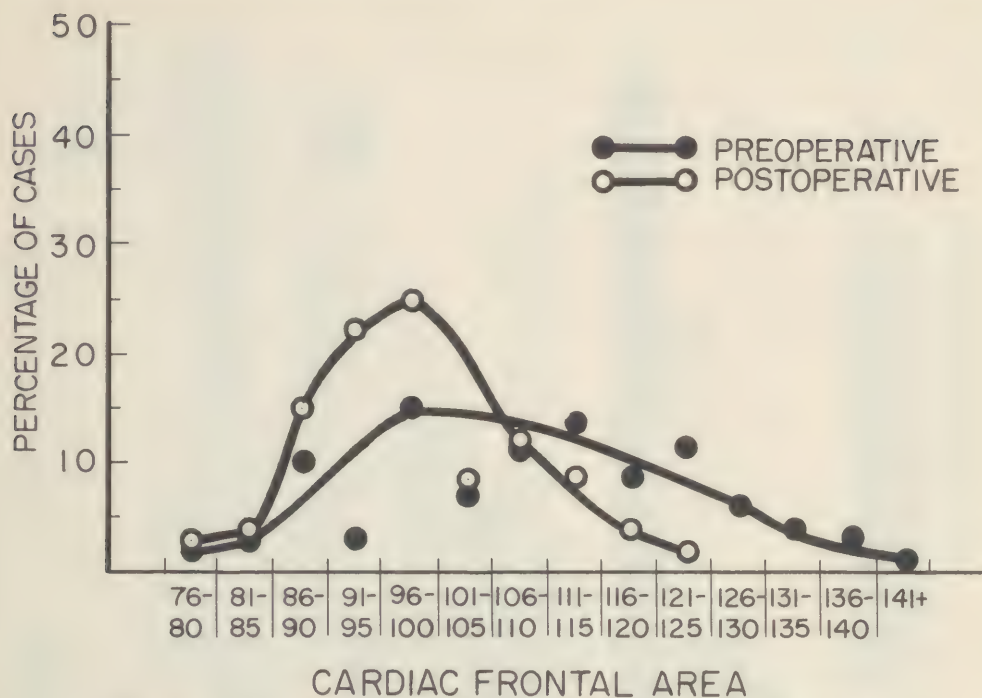
Postoperative measurements of the cardiac frontal area were made on 161 patients (Table 20, Charts 26 and 27). In contrast to preoperative values, postoperative measurements were in excess of 105 percent of the predicted size in only 26.7 percent of those tested, while in no instances were these measurements in excess of 125 percent. After operation almost two-thirds of the patients (64.6 percent) had measurements in the 85–105 percent of the predicted range, while 8.7 percent had measurements less than 85 percent of the predicted size.

On 132 patients both preoperative and postoperative measurements were made (Table 21, Chart 28). In 37.9 percent there was no essential difference in the postoperative as compared to the preoperative values. In 3.8 percent a slight increase in cardiac size was recorded after operation. Nearly 60 percent of the patients, however, showed a reduction of 6 percent or more in cardiac size after operation, while in 9.8 percent of the patients the decrease was 21 percent or more.

Influence of Special Factors on Cardiac Measurements

When the preoperative and postoperative measurements of the cardiac frontal area were compared in special categories of fistulas, wide differences immediately became apparent (Tables 19, 20, and 21, Chart 29). As a rule, patients with femoral and popliteal fistulas tended to show greater increases in the cardiac size before operation than those with fistulas in other locations, and patients with fistulas of the pelvis and lower extremities tended to show cardiac enlargements more frequently than those with fistulas in the upper part of the body. A similar, but less pronounced, difference was apparent when these two groups were compared with respect to the degree of reduction in the cardiac size after operation.

Further analysis of the data suggested a direct relationship between the size of the fistula and the degree of cardiac enlargement. Fistulas in the vessels of the leg, for instance, which were generally small as compared with fistulas of the femoral and popliteal vessels, showed less cardiac enlargement than the group with femoral and popliteal lesions. In order to evaluate this



(Postoperative interval 121-125 includes all patients with measurements in excess of 121.)

Chart 26. Distribution of measurements of cardiac frontal area (in terms of predicted area) in 153 patients before and in 161 patients after operative cure of arteriovenous fistula.

observation more exactly, the degree of cardiac enlargement was analyzed in 36 femoral and 31 popliteal arteriovenous fistulas of approximately the same duration and in which the size was known (Table 22). It was evident that those with larger fistulas tended to show more cardiac enlargement. When popliteal and femoral fistulas of roughly the same size were compared, it seemed evident that the femoral fistulas were associated with more cardiac enlargement; this appeared logical since the femoral arteries were larger in diameter and their fistulas closer to the heart. Indeed, the increase in cardiac frontal area was as great in the smaller femoral fistulas as in the larger popliteal fistulas.

A similar comparison of the preoperative cardiac measurements in a small number (34) of subclavian, axillary, popliteal, and femoral arteriovenous fistulas of approximately the same diameter (7 mm. or more) and approximately the same duration (from 3.1 to 6.5 months) supported the evidence already adduced for femoral and popliteal arteriovenous fistulas (Table 23). Although the numbers are small, the analysis indicates that femoral fistulas

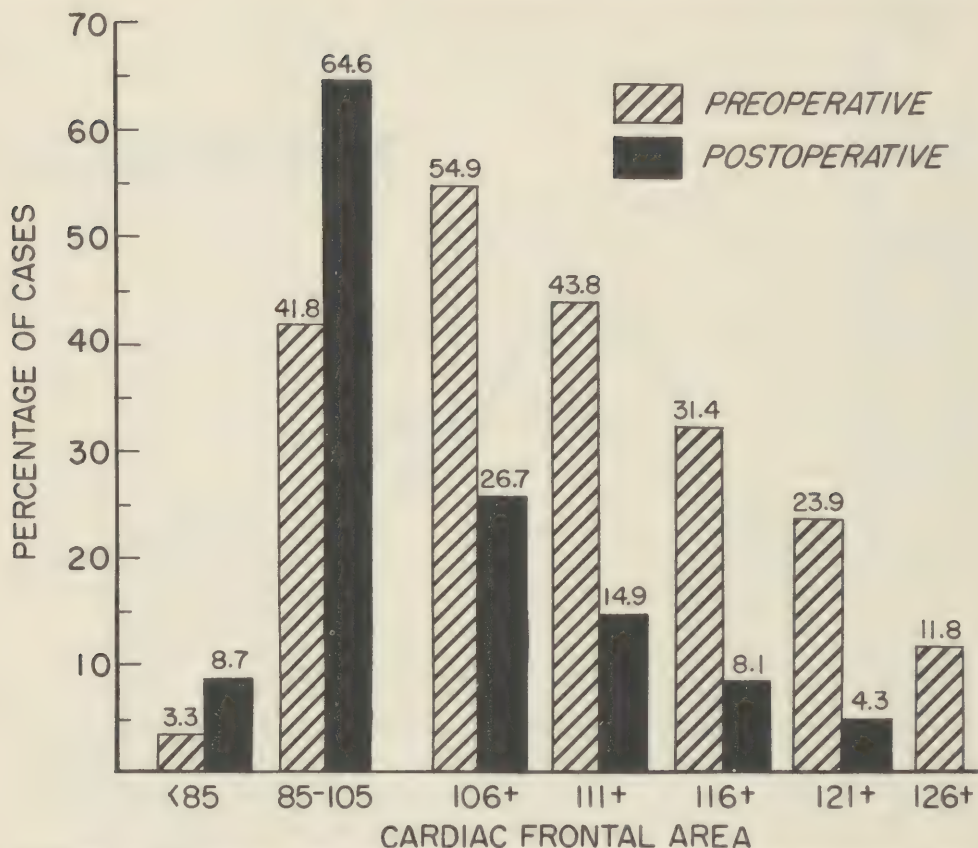


Chart 27. Proportionate distribution of measurements of cardiac frontal area in percentage of predicted area in 153 patients before and in 161 patients after operative cure of arteriovenous fistula.

TABLE 22. PROPORTIONATE DISTRIBUTION OF CARDIAC ENLARGEMENT IN RELATION TO SIZE OF FISTULA IN PATIENTS WITH POPLITEAL AND FEMORAL ARTERIOVENOUS FISTULAS

Location of fistula	Number of patients	Size of fistula	Cardiac frontal area*				
			106+	111+	116+	121+	126+
Popliteal and Femoral	40	Mm. 8+	85.0	77.5	55.0	45.0	25.0
Popliteal	17	8+	70.6	64.7	47.1	35.3	17.6
Femoral	23	8+	95.7	87.0	60.9	52.2	30.4
Popliteal and Femoral	27	<8	70.4	48.1	33.3	29.6	18.5
Popliteal	14	<8	64.3	35.7	21.4	14.3	14.3
Femoral	13	<8	76.9	61.5	46.2	46.2	23.1

*Measurements of cardiac frontal area are expressed in percentages of predicted area.

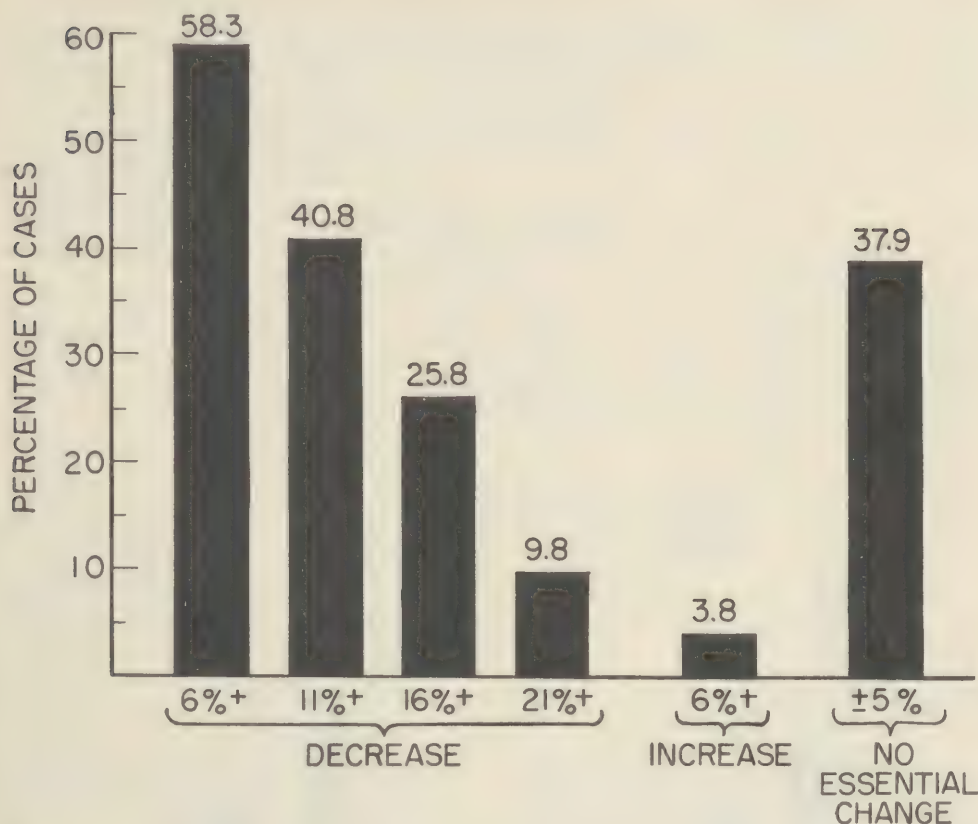


Chart 28. Proportionate distribution of alteration in cardiac frontal area in 132 patients after operative cure of arteriovenous fistula.

are likely to be associated with the greatest increases in cardiac frontal area, and subclavian and axillary fistulas with the least. The popliteal, axillary, and subclavian vessels were roughly equal in size; the femoral vessels were larger. On the other hand, the subclavian and axillary arteriovenous fistulas were closest to the heart and the popliteal fistulas the most distant.

An analysis of the possible relationship of the duration and size of the fistula to the preoperative measurements of the cardiac frontal area (Table 24) revealed that in 31 popliteal fistulas in which the time element was essentially the same, the size of the heart could be correlated with the size of the fistula; smaller fistulas were associated with smaller heart size and larger fistulas with larger heart size. Thirty-six femoral arteriovenous fistulas were similarly studied. The fistulas associated with the greatest increase in cardiac frontal area were larger fistulas of longer duration than those associated with less cardiac enlargement.

TABLE 23. PROPORTIONATE DISTRIBUTION OF PREOPERATIVE CARDIAC FRONTAL AREA IN VARIOUSLY LOCATED FISTULAS 7 MILLIMETERS OR MORE IN DIAMETER AND FROM 3.1 TO 6.5 MONTHS DURATION

Location of fistula	Cardiac frontal area*					
	<106		106-115		116+	
	Number of patients	Percent	Number of patients	Percent	Number of patients	Percent
Popliteal.....	3	27.2	4	36.4	4	36.4
Femoral.....	1	5.6	7	38.9	10	55.5
Subclavian and axillary.....	3	60.0	2	40.0	-----	0

*Measurements of cardiac frontal area are expressed in percentages of predicted area.

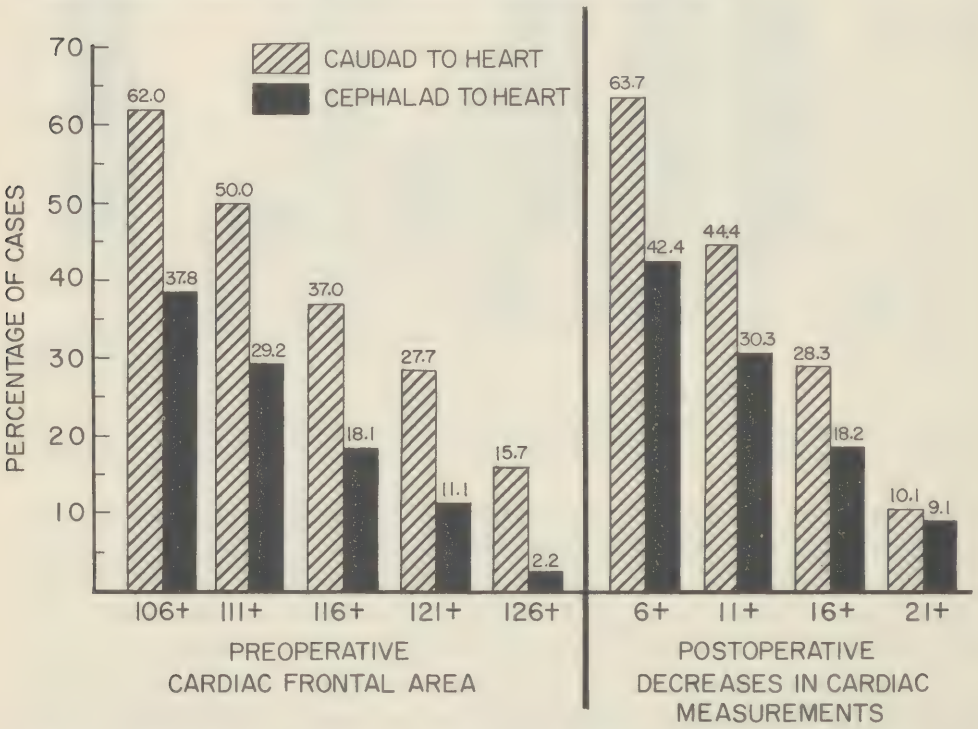


Chart 29. Comparative distribution of preoperative measurements of cardiac frontal area (in percentages of predicted values) and of postoperative decreases (percentages of preoperative values) in fistulas caudad and cephalad to the heart. The preoperative values for the fistulas of the pelvis and lower extremities caudad to the heart are based upon 108 patients and for the fistulas of the head, neck, and upper extremities cephalad to the heart in 45 patients. The postoperative values are based, for the corresponding fistulas, upon 99 and 33 patients, respectively.

When 22 popliteal and 28 femoral arteriovenous fistulas of large size (7 mm. or more in diameter) were analyzed in relation to the duration of the lesion and the increase in the measurements of the cardiac frontal area (Table 25), some relationship between the two variables appeared to exist: The group of patients in whom the greatest increases in cardiac size had occurred included the majority of cases of relatively longest duration.

TABLE 24. RELATIONSHIP OF DURATION AND SIZE OF FISTULA TO PREOPERATIVE CARDIAC FRONTAL AREA

Location of fistula	Cardiac frontal area 110% of predicted or less*					Cardiac frontal area 111% of predicted or more*				
	Number of patients	Average size of fistula	Duration of fistula		Patients with fistulas of 5 mo. duration or more	Number of patients	Average size of fistula	Duration of fistula		Patients with fistula of 5 mo. duration or more
			Range	Average				Range	Average	
Popliteal----	15	Mm. 7. 4	Months 1. 6-10. 5	Months 4. 6	Percent 40. 0	16	Mm. 9. 0	Months 2. 0-10. 0	Months 4. 6	Percent 31. 2
Femoral-----	8	6. 7	2. 0-8. 0	4. 0	12. 5	28	9. 2	1. 6-19. 0	8. 3	39. 3

*Measurements of cardiac frontal area are expressed in percentages of predicted area.

TABLE 25. RELATIONSHIP OF DURATION OF FISTULA TO PREOPERATIVE CARDIAC FRONTAL AREA IN PATIENTS WITH POPLITEAL AND FEMORAL FISTULAS OF LARGE SIZE (DIAMETER OF 7 MM.+)

Location of fistula	Cardiac frontal area 110% of predicted or less*						Cardiac frontal area 111% of predicted or more*					
	Duration of fistula (months)						Duration of fistula (months)					
	<2.5		2.6-4.0		4.1+		<2.5		2.6-4.0		4.1+	
	Number of patients	Per-cent	Number of patients	Per-cent	Number of patients	Per-cent	Number of patients	Per-cent	Number of patients	Per-cent	Number of patients	Per-cent
Popliteal -----	3	30. 0	3	30. 0	4	40. 0	1	8. 3	4	33. 3	7	58. 4
Femoral -----	1	25. 0	3	75. 0	-----	0	2	8. 3	8	33. 3	14	58. 4
Both -----	4	28. 6	6	42. 8	4	28. 6	3	8. 3	12	33. 3	21	58. 4

*Measurements of cardiac frontal area are expressed in percentages of predicted area.

Serial preoperative determinations were made in 39 patients in this series (Table 26). In 18 the cardiac frontal area was the same at the first and last examinations and in 5 the changes in terms of the predicted size were less than 5 percent in one direction or the other. In 4 other patients the heart size on the last examination had decreased by from 5 to 11 percent and in the remaining 12 it had increased by from 5 to 33 percent. It may be of interest to note that in 7 of the 14 patients in which the interval between examinations was 6 weeks or more, an increase in the size of the heart was noted on the second examination.

Serial postoperative determinations of the heart size were made in 24 patients (Table 27). In 15 there was no essential change between the first and last examination; in 1 the heart had increased in size, and in 8 there was a

decrease of 5 percent or more in cardiac size between the first and last post-operative examinations. In approximately two-thirds of the patients the interval between examinations was a month or more.

TABLE 26. COMPARISON OF CARDIAC FRONTAL AREA IN PATIENTS IN WHOM MORE THAN ONE MEASUREMENT WAS MADE BEFORE OPERATION

Location of fistula	Size	First examination		Last examination	
		Duration	Cardiac size*	Duration	Cardiac size*
	<i>Mm.</i>	<i>Months</i>		<i>Months</i>	
Femoral.....	10	1.7	100	3.2	126
Femoral.....	5	2.8	123	3.2	123
Femoral.....	9	3.0	81	4.0	114
Femoral.....	9	1.0	110	2.0	110
Femoral.....	7	2.4	124	3.6	124
Femoral.....	15	9.2	102	12.0	122
Femoral.....	8	5.6	118	6.5	118
Femoral.....	8	3.7	118	4.7	110
Femoral.....	10	3.0	114	4.5	114
Femoral.....	6	3.0	126	4.0	126
Femoral.....	6	3.5	106	7.0	127
Femoral.....	10	2.0	111	6.0	111
Femoral.....	10	3.0	104	4.0	124
Femoral.....	12	3.0	121	4.3	121
Popliteal.....	8	1.5	105	3.0	116
Popliteal.....	5	5.0	95	6.0	108
Popliteal.....	10	2.7	127	3.7	127
Popliteal.....	5	4.0	108	5.8	108
Popliteal.....	7	1.4	93	2.5	93
Popliteal.....		4.0	114	5.8	110
Popliteal.....		4.0	119	4.8	121
Popliteal.....	10	3.5	125	4.5	125
Popliteal.....	5	4.2	110	6.4	130
Popliteal.....	10	6.4	132	8.0	132
Popliteal.....	10	3.7	105	4.6	112
Popliteal.....	10	2.7	113	4.0	102
Popliteal.....	15	3.4	125	4.4	125
Profunda femoris.....	4	5.0	92	6.0	92
Superior gluteal.....	<5	5.3	100	6.3	92
Obturator.....	<5	3.0	116	5.0	107
Geniculate.....	<5	5.0	103	6.0	103
Posterior tibial.....	<5	2.3	101	4.0	97
Posterior tibial.....	<5	1.8	97	2.7	97
Posterior tibial.....	<5	2.5	84	3.5	90
Posterior tibial.....		3.2	90	4.5	90
Subclavian.....	10	3.1	97	4.5	100
Axillary.....		3.0	88	3.8	90
Internal carotid.....		1.0	94	3.0	115
Ulnar.....		7.0	107	15.0	118

*Measurements of cardiac frontal area are expressed in percentages of predicted area.

TABLE 27. COMPARISON OF CARDIAC FRONTAL AREA IN PATIENTS IN WHOM MORE THAN ONE MEASUREMENT WAS MADE AFTER OPERATION

Location of fistula	First examination		Last examination	
	Interval after operation	Changes in cardiac size from preoperative values*	Interval after operation	Changes in cardiac size from preoperative values*
	<i>Months</i>		<i>Months</i>	
Femoral.....	0.2	12% decrease.....	6.0	19% decrease.
Femoral.....	0.5	21% decrease.....	2.2	21% decrease.
Femoral.....	2.2	4% increase.....	3.7	4% increase.
Femoral.....	0.5	14% decrease.....	3.5	16% decrease.
Femoral.....	0.3	12% decrease.....	4.7	17% decrease.
Femoral.....	1.0	0.....	4.7	17% decrease.
Femoral.....	0.4	8% decrease.....	2.3	16% decrease.
Femoral.....	0.3	30% decrease.....	2.8	30% decrease.
Popliteal.....	1.5	21% decrease.....	2.5	16% decrease.
Popliteal.....	1.3	12% decrease.....	4.0	12% decrease.
Popliteal.....	1.0	15% decrease.....	2.6	15% decrease.
Popliteal.....	0.4	4% decrease.....	7.0	4% decrease.
Popliteal.....	0.4	13% decrease.....	8.0	13% decrease.
Posterior tibial.....	0.7	16% decrease.....	1.6	16% decrease.
Posterior tibial.....	0.3	0.....	0.8	9% decrease.
Geniculate.....	0.5	2% decrease.....	1.2	6% decrease.
Subclavian.....	1.5	0.....	3.0	1% decrease.
Subclavian.....	1.0	4% decrease.....	1.5	0.
Axillary.....	0.4	0.....	1.0	0.
Axillary.....	0.7	4% decrease.....	4.0	20% decrease.
Brachial.....	0.5	16% increase.....	1.5	8% increase.
Ulnar.....	0.2	24% increase.....	2.0	24% increase.
Ulnar.....	1.0	13% decrease.....	1.6	13% decrease.
Subscapular.....	0.1	8% decrease.....	1.0	20% decrease.

*Alterations are expressed in percentages of variation from the preoperative value.

Finally, the response of the pulse, systolic and diastolic blood pressure, and pulse pressure to temporary occlusion of the fistula was correlated with the frontal cardiac measurements in terms of the predicted heart size (Chart 30). Only 20 to 30 percent of the patients who showed a minimal or moderate response to occlusion of the fistula had distinct degrees of cardiac enlargement, while between 47 and 69 percent of those who showed maximal response to it also showed maximal increases in the size of the heart.

COMMENT

Although it is now well recognized that arteriovenous fistulas are likely to cause an increase in the cardiac output, enlargement of the heart, and in some instances cardiac failure, it is interesting to note that these potentialities have been appreciated only during the last 25 years.

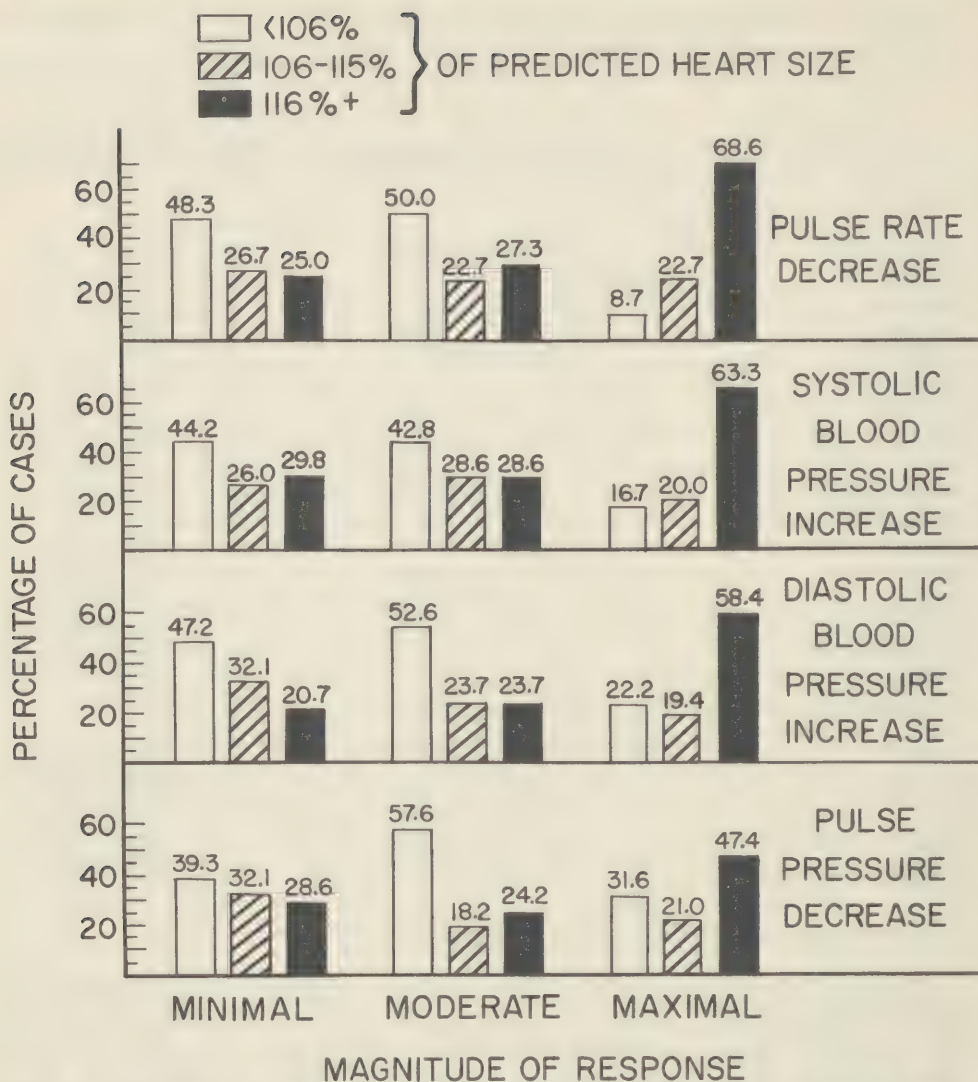


Chart 30. Comparative measurements of cardiac frontal area (in percentages of predicted value) in relation to magnitude of response of pulse and blood pressure to temporary occlusion of the fistula. The measurements are based upon 145 patients.

In a discussion of arteriovenous fistulas in 1915, Osler² wrote:

... we all agree, I think, with the conclusion arrived at by Soubotitch, senior surgeon of the Belgrade State Hospital, from his experience in the Balkan War, 'that arteriovenous aneurysms should be operated upon, as they offer small prospect of spontaneous cure, although they often remain stationary for a long time and cause relatively little trouble.'

² Osler, Sir W.: Remarks on arterio-venous aneurysm. *Lancet* 1: 949-955, 8 May 15.

Osler's convictions on the matter, however, must have been lukewarm at best, since in reference to one of his own patients he wrote:

The tumor had increased, and the question was whether it was safe to leave him alone. This was the policy I urged strongly. Twice he *narrowly escaped operation*. [Italics not in original.]

When he enumerated the end results of arteriovenous fistulas Osler did not mention the possibility of cardiac strain and failure, although later in the same paper he did state:

Remote effects on the general circulation are rare, particularly in aneurysms of the vessels of the head and arms. One of my patients . . . died from heart disease which may have had some connection with his long-standing lesion.

As Reid³ wrote in 1925:

. . . it has taken the profession a long time to establish a cause and effect between arteriovenous fistulas, in vessels smaller than the aorta, and the cardiac disturbances they produce. So often we remain blind to the insidious conditions that shorten the duration of human lives. Although Osler for years followed two cases of arteriovenous aneurysms (one axillary, the other femoral) in which the patients died from cardiac disease at the early ages of 29 and 46, he was never, unless possibly shortly before his death, convinced of the causal relationship existing between the two conditions; and for a long time he counselled against operations on arteriovenous aneurysms.

Since Osler was the acknowledged leader of his profession, there can be little doubt, as Reid intimates, that the best medical opinion of his day was in agreement with his point of view.

Between 1920 and 1924 Reid,⁴ Matas,⁵ and Holman⁶ all pointed out the profound effects of arteriovenous fistulas upon the heart. Their clinical experience was necessarily limited by the infrequency of these lesions, but their observations were confirmed by the important experimental studies of Reid⁷ and Holman.⁸ Since that time a number of instances of cardiac enlargement and cardiac failure in association with arteriovenous fistulas have been placed on record, particularly in recent years. Though most of the instances of frank cardiac failure have occurred in patients with large arteriovenous fistulas of long duration, a number have been recorded in which failure occurred soon after the appearance of the fistula. Mason,⁹ for example, reported a remarkable case in which failure occurred within a few weeks after the appearance of a traumatic subclavian arteriovenous fistula.

³ Reid, M. R.: Abnormal arteriovenous communications, acquired and congenital; effects of abnormal arteriovenous communications on the heart, blood vessels and other structures. *Arch. Surg.* 11: 25-42, Jul 1925.

⁴ Reid, M. R.: Effect of arteriovenous fistula upon the heart and blood vessels. *Bull. Johns Hopkins Hosp.* 31: 43-50, Feb 1920.

⁵ Matas, R.: On the systemic or cardiovascular effects of arteriovenous fistulae; a general discussion based upon the author's surgical experience. *Tr. South. S. A.* 36: 623-681, 1923.

⁶ (1) Holman, E.: The physiology of an arteriovenous fistula. *Arch. Surg.* 7: 64-82, Jul 1923.

(2) Holman, E.: Experimental studies in arteriovenous fistulas; cardiac dilatation and blood vessel changes. *Arch. Surg.* 9: 856-879, pt. 2, Nov 1924.

⁷ See footnote 4, above.

⁸ See footnote 6, above.

⁹ Mason, J. M.: Extreme cardiac decompensation following traumatic arteriovenous fistula of left subclavian vessels. *Am. J. Surg.* 20: 451-473, May 1933.

Because most recorded cases of arteriovenous fistulas concern individuals or small groups, the literature supplies little information concerning the incidence of cardiac enlargement in patients with this condition. Holman¹⁰ noted that cardiac dilatation and hypertrophy, although they had been mentioned in only 4 percent of the 447 cases collected by Callander,¹¹ had been present in 6 of the 21 cases which he himself reviewed from the Johns Hopkins Hospital.

Postoperative decreases in the cardiac measurements have also been recorded. Pendergrass¹² examined 32 patients in whom arteriovenous fistulas had been removed surgically and found that 27 showed an average decrease of 1.18 cm. in the cardiac diameter. One of the 5 remaining patients had an increase in cardiac size after operation and in the other 4 patients there was no essential change.

The method proposed by Ungerleider and Gubner¹³ for measuring the frontal area of the heart has proved as reliable as any other method devised for this purpose and was used in this study. In calculating the predicted frontal area, the height and weight of the patient on admittance to the hospital were employed and the values so calculated were used in each patient for determining the percent of the predicted value in all subsequent examinations. Had the predicted value been recalculated at each subsequent examination, apparent decreases in the cardiac frontal area would probably have been observed in most patients even if no change had actually occurred because most of the patients gained weight after they had been admitted to the vascular center, and, according to the tables for estimation, the predicted frontal area for a patient of any given height increases as the weight increases.

It is unfortunate that no "normal" values in a similar group of young soldiers without fistulas and in a comparable state of nutrition were available for study. The tables used for determination of the predicted cardiac frontal area use 100 percent as normal, and it is generally accepted that values which differ by more than 10 percent from those predicted should be regarded as abnormal. Had this 100 percent been used as normal in this series, a large number of the postoperative measurements would have seemed less than normal. An analysis of the final postoperative measurements of the cardiac frontal area in 119 patients cured of arteriovenous fistulas showed that they did indeed tend to center around 95 percent of the predicted values rather than 100 percent. Those which were beyond the limits of ± 10 percent of the control values were evenly distributed, about one-half above and about one-half below these levels. The 119 patients used for analysis did not include any in

¹⁰ See footnote 6 (1), p. 221.

¹¹ Callander, C. L.: Study of arteriovenous fistula with an analysis of 447 cases. *Ann. Surg.* 71: 428-459, Apr 1920.

¹² Pendergrass, R. C.: Cardiac changes in arteriovenous fistula. *Am. J. Roentgenol.* 53: 423-431, May 1945.

¹³ See footnote 1, p. 207.

which there was marked preoperative enlargement since it was felt that in such patients hypertrophy as well as dilatation might have occurred, with some degree of enlargement persisting after operation.

In these studies from the vascular center of Mayo General Hospital evidence of enlargement of the heart was demonstrable in about 50 percent of the 185 young patients with peripheral arteriovenous fistulas of relatively short duration. This fact was confirmed by evidence of measurable reduction in cardiac size after operation in a comparable percentage.

The data derived from this investigation tend to confirm certain opinions, previously expressed, as to factors important in the development of cardiac enlargement in the presence of arteriovenous fistulas. These opinions, although based primarily upon experimental work, were supplemented, at least in part, by clinical observations. The conclusions drawn at this vascular center may be stated as follows:

1. In patients with arteriovenous fistulas some relationship appeared to exist between the degree of cardiac enlargement and the size of the fistula, particularly when it was located in vessels of the pelvis and lower extremities. It should be noted, however, that the number of patients involved in this study was small.

2. A relationship was also evident between the duration of the fistula and the degree of cardiac enlargement. When appropriate samples of femoral and popliteal fistulas were used for comparison, with variable factors properly controlled, it was evident that cardiac enlargement varied directly with the duration of the lesion. Moreover, when roentgenograms were made in a series at intervals of 6 weeks or more before operation, 50 percent of the patients in this group showed on the last examination a demonstrable increase in cardiac size as compared with the earlier examination.

3. The data in this series concerning changes in the size of the heart in association with femoral and popliteal arteriovenous fistulas tend to support the opinion, rather generally held, that the nearer the fistula is to the heart, the greater is the likelihood of early cardiac enlargement. Not too much importance, however, can be attached to this relationship since the caliber of the involved vessels may also have played a part. Certain of the experimental work cited to support the thesis that the distance of the fistula from the heart has an important influence on the associated cardiac enlargement can be challenged for the same reason, that is, failure to take into consideration the size of the artery selected for communication with the vein. As a rule, the closer to the heart the fistula was created in these experimental studies, the larger was the artery selected for the communication. It is apparent that if the diameter of the fistula exceeds that of the parent artery, the blood flow through the fistula will be limited in part by the size of that artery.

4. These data also demonstrated that another consideration was more important in the production of cardiac enlargement than the proximity of the fistula to the heart, namely, whether it was cephalad or caudad to the heart. Both the frequency and degree of cardiac enlargement were greater in fistulas of the pelvis and lower extremities than in fistulas of the head, neck, and upper extremities. In this connection, it is curious that in years past a number of authors, although they had only a limited number of patients on whom to base the observation, made the same point. Thus Osler,¹⁴ who, as previously pointed out, was not impressed by the possible relationship between arteriovenous fistulas and cardiac strain, stated that remote effects upon the general circulation were extremely uncommon, "particularly in aneurysms of the vessels of the head and arms."

The data in this study seem to permit two clinical conclusions. The first is that a marked change in the pulse or blood pressure upon temporary occlusion of an arteriovenous fistula is likely to be associated with an early and significant increase in the frontal area of the heart. The second is that without other information it is possible to gain some idea of the likelihood of early cardiac enlargement from the location of the fistula alone. Though a considerable increase in the size of the heart may occur relatively soon after the development of an arteriovenous fistula involving any reasonably large vessel in any portion of the body, the alteration is particularly likely to be associated with fistulas in the great vessels caudad to the heart.

¹⁴ See footnote 2, p. 220.

CHAPTER VII

Arterial Aneurysms and Arteriovenous Fistulas Technical Consideration in Their Surgical Management, With Special Reference to Exposure of the Blood Vessels

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and

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The safe and successful accomplishment of operations on blood vessels requires careful anatomic exposure. Young surgeons assigned to the vascular centers established in the Zone of Interior were frequently woefully lacking in anatomic knowledge. In years past, textbooks have dealt with anatomic considerations as matters of first importance and devoted considerable space to proper approaches to the blood vessels and methods of ligation. When World War II began, however, textbooks of surgery were concerned for the most part with anatomy as applied to diagnosis and treatment, and the young military surgeon could get no adequate guidance from them. Though many of these men had served internships and even surgical residencies they lacked anatomic knowledge as it relates to the peripheral nerves, blood vessels, and the musculature of the extremities.

To overcome this lack it was necessary for skilled vascular surgeons assigned to the centers to train these officers not only in the specialized techniques of vascular surgery, but often in the elementary details of such techniques.

In the following pages are set forth the important principles and techniques taught and practiced in the vascular centers.

GENERAL PRINCIPLES

One of the cardinal principles of the surgery of aneurysms is that incisions must provide easy and complete access to the vessels involved. The planning of an approach which permits isolation and control of the involved vessels is often more important than the surgical treatment of the lesion itself. Furthermore, the incision must be so placed that by lengthening it the vessels distal and proximal to the site of the suspected lesion are made accessible without difficulty. Unless the plan of exposure is an integral part of every procedure, hemorrhage may so interfere that the operation cannot be carried out successfully; even death of the patient may result. Whenever the exposure and control of major vascular trunks are regarded as preliminary steps to the repair of aneurysms and arteriovenous fistulas, the hazards of operation are greatly reduced.

These considerations do not obviate in any sense, however, the advisability of planning skin incisions which yield a good plastic result, which do not cross normal skin folds and creases, and which minimize the hazards of keloid formation, scarring, and contractures—provided such incisions sacrifice nothing essential in regard to the exposure of the vessels. Adequate exposure is not necessarily achieved by an incision which lies directly over the vessels involved; only rarely does a properly placed plastic incision offer any real limitation upon the achievement of easy and complete access to the vessels.

VESSELS OF THE LOWER EXTREMITY

Femoral Vessels

The guide to the superficial femoral vessels is the sartorius muscle which in the upper portion of the thigh lies lateral to the vessels, and in the middle and lower portion overlaps the vessels in their course in Hunter's canal. The upper popliteal and lower femoral vessels are best reached through an incision just anterior to the sartorius muscle. When the knee is flexed and the thigh rotated externally, the sartorius is easily displaced posteriorly upon opening the deep fascia (Fig. 17).

For lesions of the common femoral artery, and occasionally for those of the proximal portion of the femoral or profunda femoris artery, an oblique incision just below Poupart's ligament is preferred. If the lesion is too high to permit adequate exposure without proximal extension of a longitudinal incision, it is preferable to curve the incision up along the inguinal fold rather than to cross the crease.

Popliteal Vessels

Although it is common practice to explore the popliteal vessels through a longitudinal incision crossing the popliteal crease, a high percentage of patients thus treated subsequently develop heavy scars or keloids, contractures, and even ulcerative lesions. These sequelae are disabling, their remedy by plastic procedures is time-consuming and not always successful, and exposure of the popliteal vessels can quite as well be secured by more desirable methods.

Lesions of the first portion of the popliteal and of the femoropopliteal vessels can be exposed by a longitudinal anteromedial incision extending down to the knee. When the thigh is rotated externally and the knee flexed, the sartorius muscle is relaxed and easily retracted. The femoral vessels are then accessible proximal to the point at which they pass under the adductor tendon and the popliteal vessels are accessible to the point at which they emerge beneath this tendon.

When the lesion lies more distally, in the midpopliteal space, some type of transverse incision crossing the popliteal space in one of the natural creases is used (Fig. 18). A simple transverse incision is sometimes adequate, particularly when a large saccular aneurysm is approached by the intrasaccular route and

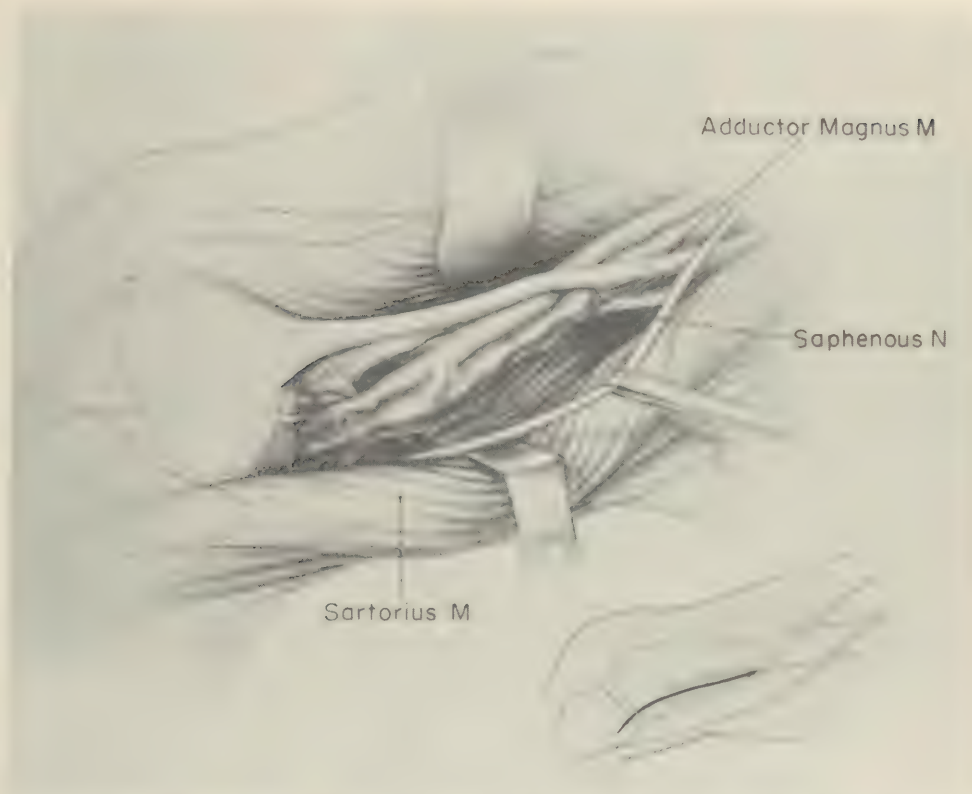


Figure 17. Exposure of lower femoral and popliteal vessels by medial approach anterior to sartorius muscle.

the blood supply is controlled by a tourniquet. More often the incision must be extended upward along the medial aspect of the thigh and downward along the lateral surface of the leg (Fig. 18A). The skin flaps are reflected and the fascia incised longitudinally in the midline. The biceps is retracted laterally and the semimembranosus and semitendinosus are retracted medially. After the tibial and peroneal nerves are identified, which is not difficult, the vein and artery are readily accessible.

When the lesion is in the distal portion of the popliteal space, exposure by retraction or division of the heads of the gastrocnemius muscle is difficult. Such a procedure entails a definite hazard since the innervation of the gastrocnemius, plantaris, and popliteus muscles may be injured.

The difficulty is obviated and exploration made easy by the use of an L-shaped incision crossing the lateral half of the popliteal space and extending downward along the posterolateral aspect of the calf (Fig. 18C and D). The fascia is divided beneath the skin incision. The lateral head of the gastrocnemius along with the plantaris is retracted, as is the medial head. The popliteal

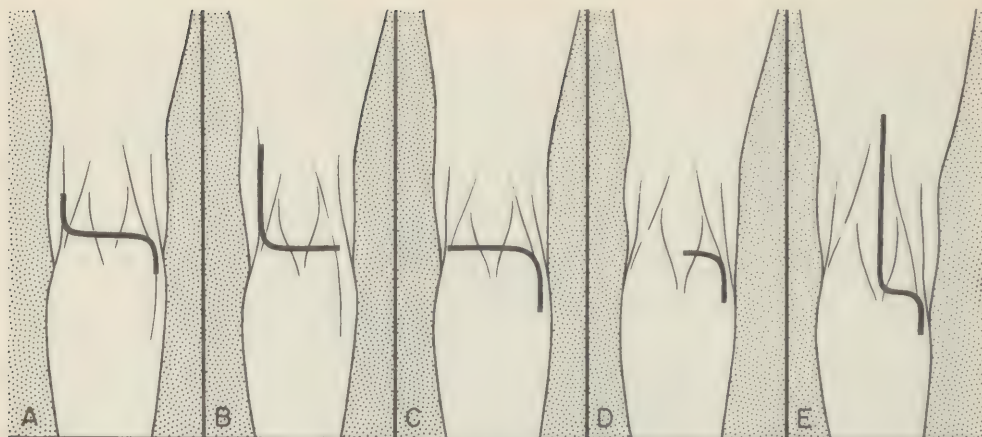


Figure 18. Skin incisions for exploration of popliteal vessels. A. Incision for lesion in popliteal vessels in midpopliteal space. B. Incision for lesion higher in popliteal fossa. C, D. Incisions for lesions of distal popliteal vessels. E. Modified incision useful for exposure of associated nerve lesion.

artery and vein and the tibial nerve are thus brought into view and can be followed as they cross over the popliteus muscle and pass through the tendinous arch of the soleus muscle (Fig. 19).

When the lesion is in that portion of the vessels covered by the soleus muscle, the skin incision must be extended down the leg. Exposure of the vessels generally necessitates division of the lateral fibers of the soleus attached to the fibula, with or without division of that portion arising from the head of the fibula. Sometimes the vessels can be exposed satisfactorily by incising the muscle longitudinally directly over the vessels.

Vessels of the Leg

In general, exposure of vascular lesions in the lower extremity can be accomplished without difficulty by the use of properly placed longitudinal incisions which do not cross skin creases and which therefore heal without sequelae. This is particularly true of lesions of the lower third of the leg which are easily reached by direct approach along the posteromedial aspect. The incision is begun one fingerbreadth posterior to the border of the tibia and can be carried upward by detaching a portion of the soleus muscle from its origin on the tibia.

Lesions of the posterior tibial vessels and of the anterior tibial and peroneal vessels in the upper part of their course present a different problem. To distinguish clinically which of these vessels is involved is frequently impossible because of their close proximity to each other, but difficulties of exposure are the same for all. The tibia and fibula are closely apposed in this area and there is a dense interosseous membrane between them. Hemorrhage is a serious

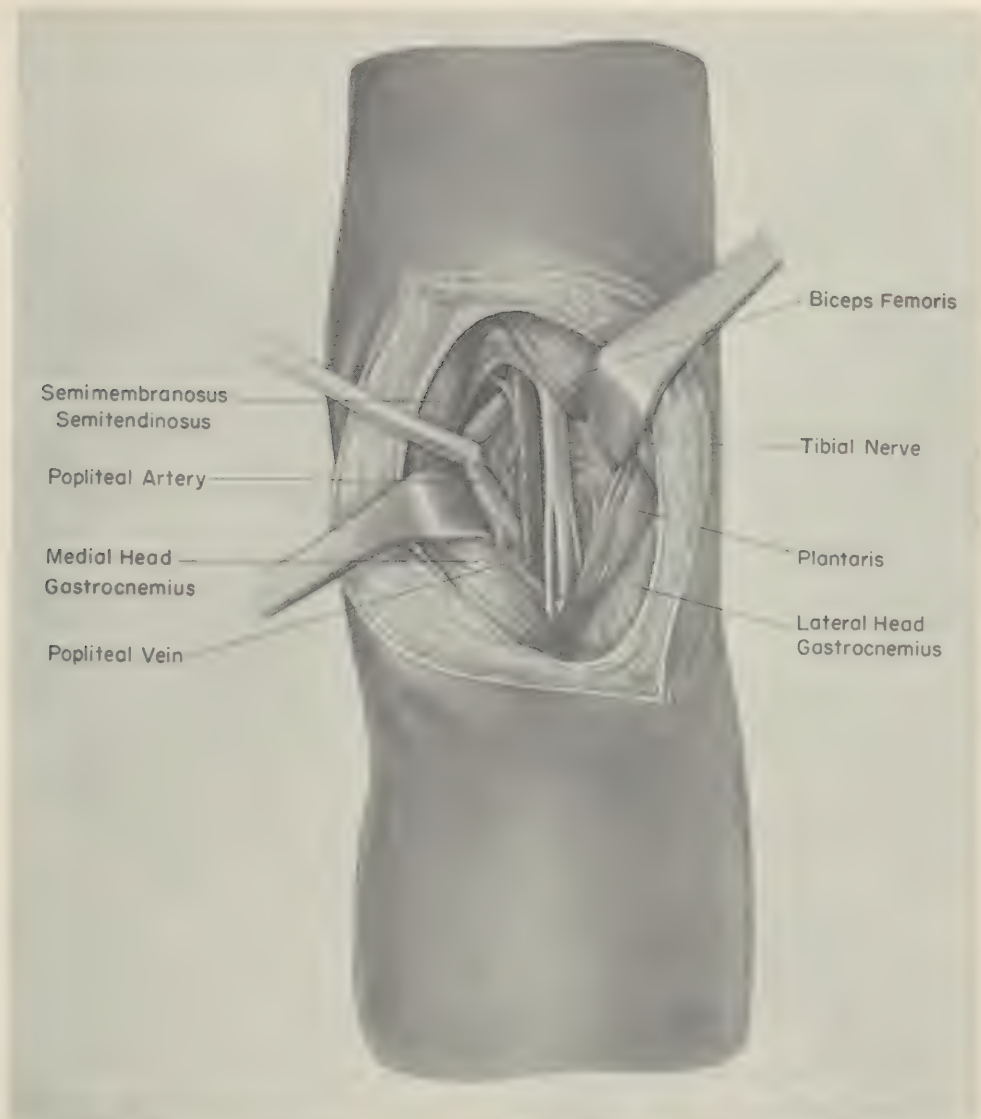


Figure 19. Exposure of the popliteal vessels. The lateral and medial heads of the gastrocnemius are retracted and nerve and vessels are seen lying upon popliteus muscle and as they enter the soleus.

possibility. The rich collateral anastomosis which develops as the result of an arteriovenous communication, together with dilatation of the vessels including those which perforate the interosseous membrane, demands direct visualization of these vessels and their careful ligation and division. Otherwise the retraction of vascular channels through the interosseous membrane may

result in serious or even uncontrollable hemorrhage. This would necessitate a second incision along the front of the leg, or the removal of the fibula in the presence of hemorrhage and at an inopportune time during the course of the operation. Deliberate removal of the upper portion of the fibula to secure adequate exposure is often, therefore, the part of wisdom.

At the vascular centers in World War II the incision used for exposure of the posterior tibial and upper portion of the anterior tibial and peroneal vessels was a modification of the technique described by Henry¹ in 1927. In this procedure the upper portion of the fibula is removed subperiosteally which insures continued stability of the knee joint. An additional advantage of this method is that the peroneal nerve, which is frequently injured concomitantly with the blood vessels, can be exposed and treated as necessary through the same incision.

Continuous spinal is the anesthetic of choice for this operation. The patient lies on the unaffected side with the knee slightly flexed. A pneumatic tourniquet is applied to the thigh but is not inflated unless severe hemorrhage occurs.

The incision is begun about 2 inches above the head of the fibula and carried distally as far as may be indicated by the position of the aneurysm. After the skin and superficial fascia are divided at the upper end of the incision, the deep fascia is opened at the medial edge of the biceps tendon. The common peroneal nerve is exposed, and a rubber strip passed around it for aid in immobilization (Fig. 20). Division of the deep fascia is continued downward along the course of the nerve at the posterior margin of the biceps tendon. The fascial origin of the peroneus longus muscle, which lies directly over the groove in which the nerve passes forward across the neck of the fibula, is divided. A definite plane, the lateral intermuscular septum, which lies between the soleus muscle posteriorly and the peroneus longus muscle anteriorly, is easily developed. When the muscles are separated the lateral border of the fibula immediately comes into view. The periosteum is readily stripped from the fibula by sharp dissection, aided by a periosteal elevator, and the fibula divided by means of a Gigli saw. The removal of the head subperiosteally is more difficult and is best carried out by dissection with a sharp knife. The blade of the knife is kept *directly* against the bone and the peroneal nerve is retracted completely out of the field of incision. The removal of the head and of the upper portion of the fibula exposes the lower end of the popliteal artery with its terminal branches, namely, the posterior tibial, anterior tibial (Fig. 21), and peroneal vessels. These are easily seen when the soleus muscle is retracted posteriorly and the peroneus longus anteriorly.

As the first step in excision of the arteriovenous fistula, the artery proximal to the fistula is secured. A ligature is passed around it to control any possible bleeding, but is left untied. The vessels distal to the lesion are isolated,

¹ Henry, Arnold K.: Exposure of Long Bones and Other Surgical Methods. Bristol, John Wright and Sons, Ltd, 1927.



Figure 20. Resection of head of fibula for exposure of tibial and peroneal vessels. Note sharp dissection of periosteum covering head of fibula and complete mobilization of common peroneal nerve.

ligated, and divided. Following this the proximal artery is ligated and divided. The fistula is then removed from below upward, all communicating vessels being ligated and divided. The proximal vein is divided as the last step in the operation. It is of utmost importance that the region of the fistula be avoided until its principal blood supply is completely controlled.

The resected portion of fibula is not replaced. The question of the stability of the knee joint naturally arises following removal of the insertion of the fibular collateral ligament, but none of the patients in whom the operation was performed in the vascular centers had any complaints referable to the knee joint on the operated side. Furthermore, examination failed to reveal any loss of stability. Comparison of the fibular collateral ligaments by palpation, with the ligament under stress, usually disclosed as tense a ligament on one side as on the other.

Whenever possible, incisions on the sole of the foot are to be avoided since the scar is usually painful when the foot is bearing weight. Approach to the plantar vessels is through an incision on the medial aspect of the foot. The

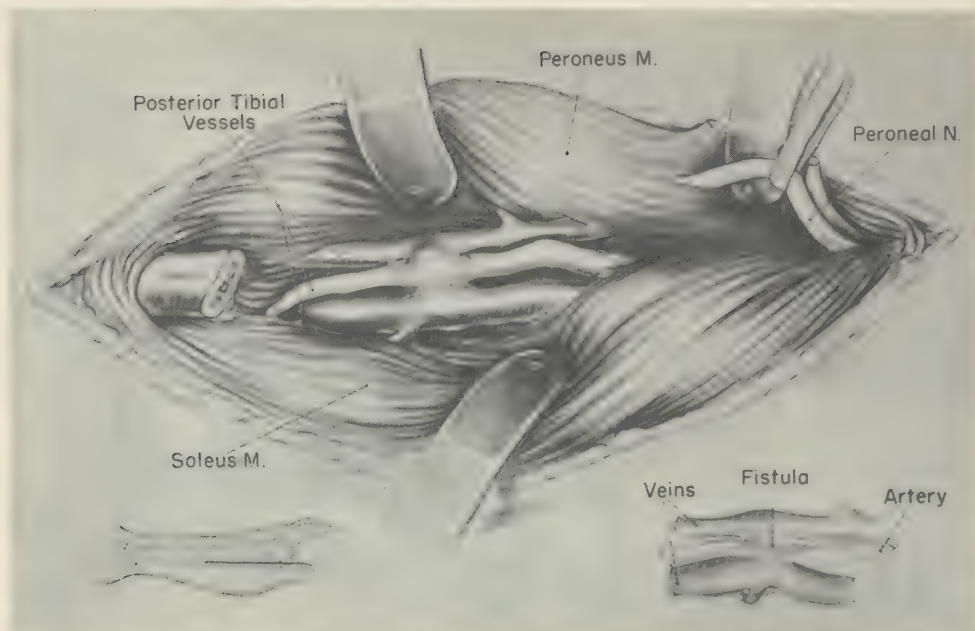


Figure 21. Exposure of arteriovenous fistula of posterior tibial vessels by removal of upper third of fibula. Insert shows line of incision.

abductor hallucis muscle is detached from its origin after which the vessels, with the tibial nerve, are easily traced into the deeper structures of the foot (Fig. 22).

VESSELS OF THE UPPER EXTREMITY

Axillary Vessels

For lesions involving the axillary vessels an incision is made over, and parallel to, the upper fibers of the pectoralis major muscle beginning about the midportion of the clavicle. If the first portion of the axillary vessels is to be exposed, usually all that is necessary is to separate the upper fibers of the pectoralis major through this type of incision and to retract or transect the muscle through its insertion, the pectoralis minor. If the distal portion of the axillary vessels is involved, the incision described is continued out over the insertion of the pectoralis major muscle and this muscle is divided through its tendinous insertion (Fig. 23).

Often the incision used for exposure of the first portion of the brachial vessels is adequate for the exposure of the distal end of the axillary vessels. The incision begins over the insertion of the pectoralis major muscle, curves down the inner aspect of the arm distal to the axilla to the region of the neurovascular bundle, and then downward for a short distance over the course of

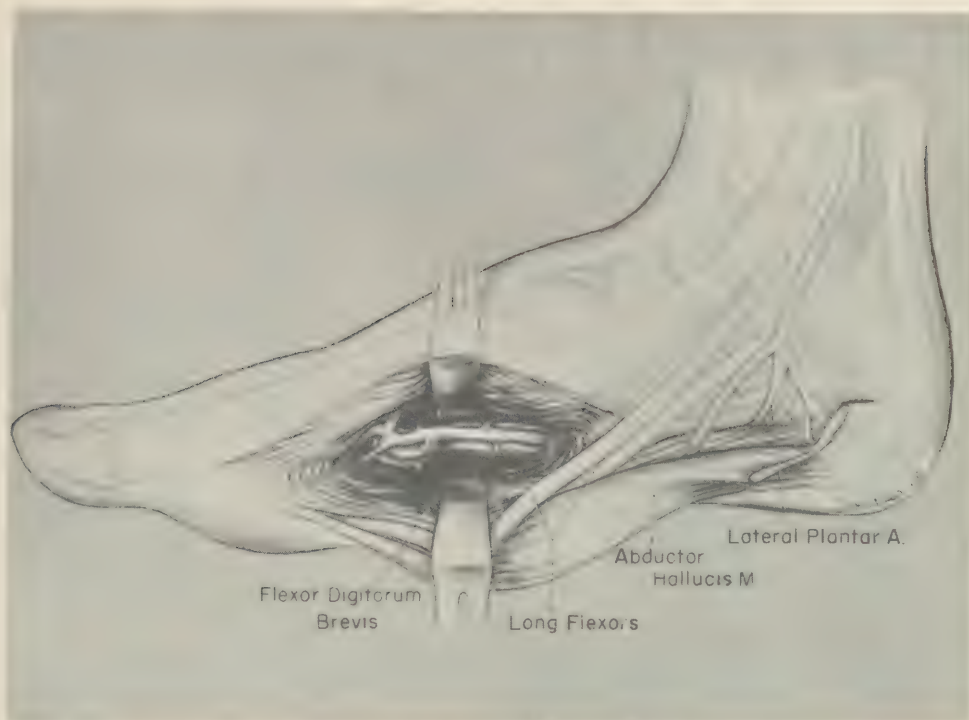


Figure 22. (After Henry.) Exposure of plantar vessels through medial approach, which is facilitated by detachment of abductor hallucis muscle from its origin.

these vessels (Fig. 24). When the skin flaps are reflected the distal portion of the axillary vessels and the first portion of the brachial vessels are readily accessible. Incision through the axilla is thus avoided. This is most desirable since keloids, heavy scars, and disabling contractures are particularly troublesome in this region. An additional advantage of the incision described is that it permits exposure of any concomitant nerve lesions.

Vessels of the Antecubital Fossa

The brachial vessels are satisfactorily approached for most of their course on the inner aspect of the arm through longitudinal incisions overlying their course. The biceps muscle is used as a guide. Lesions in the first portion of the brachial vessels are best handled by an incision which does not cross the axilla. This incision is also used for exposure of the subclavian and axillary arteries (q. v.).

Lesions in and near the antecubital fossa are exposed through incisions similar to those employed in the popliteal fossa. A transverse incision is made across this space in the line of a natural skin crease. Depending upon the requirements in the special case under treatment, it is extended upward

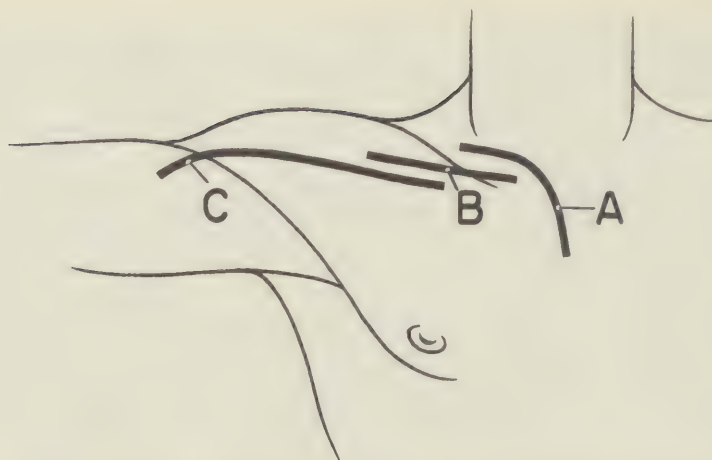


Figure 23. Incisions for exposure of A innominate, B subclavian, and C axillary vessels.

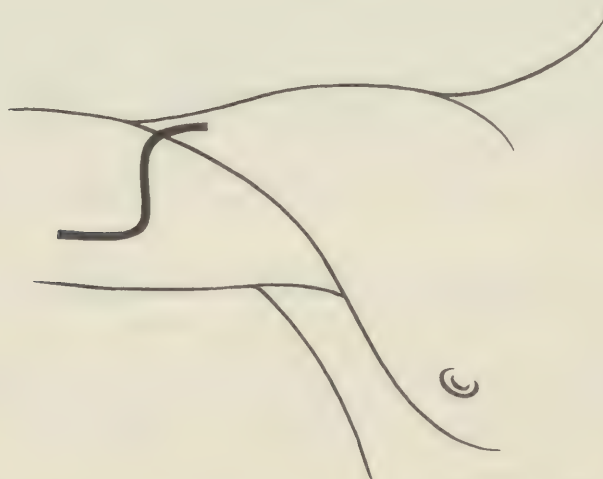


Figure 24. Incision for exploration of distal portion of axillary, and first portion of brachial, vessels.

for a short distance along the anteromedial aspect of the arm or downward along the anterolateral aspect of the forearm (Fig. 25). The skin flaps are reflected. The communications between the cephalic and basilic veins are divided and the lacertus fibrosus severed. The cephalic vein and the lateral antebrachial cutaneous nerve are retracted laterally, and the basilic vein and medial antebrachial cutaneous nerve, medially. The brachial artery and vein, with the median nerve, then come into full view (Fig. 26) and can easily be exposed down to a point below their bifurcation into radial and ulnar branches.

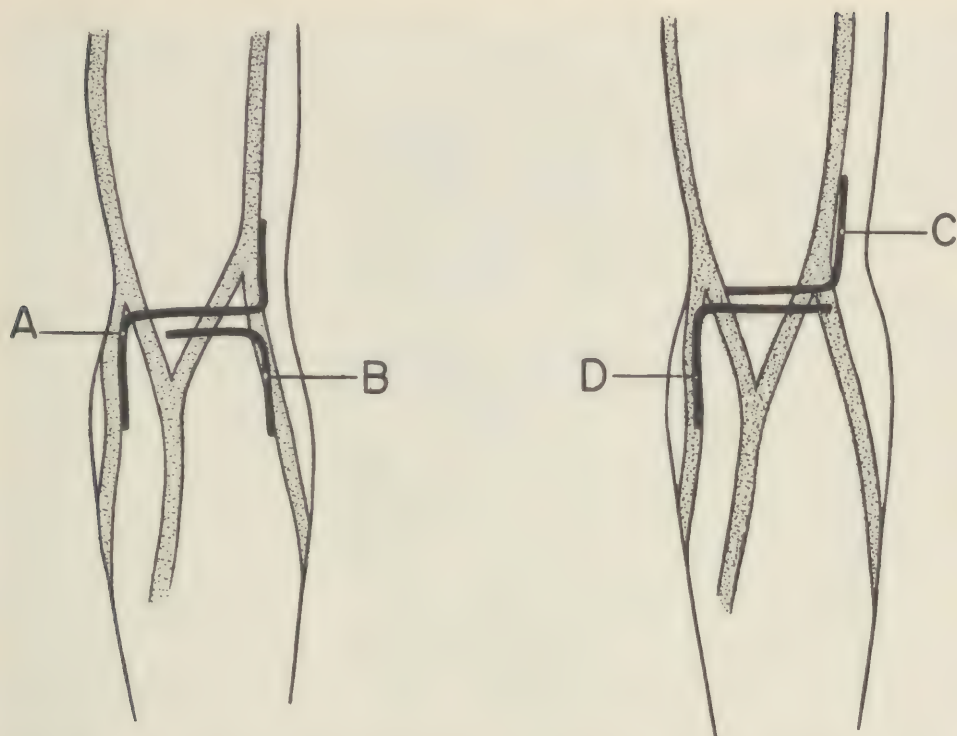


Figure 25. Incisions for exposure of vessels in antecubital fossa. A. Usual incision. B. Incision for lesion presumed to be in proximal portion of ulnar vessels. C. Incision for lesion of brachial vessels just proximal to antecubital crease. D. Incision for exploration of distal end of brachial, or proximal end of radial, vessels.

When the lesion is in the proximal portion of the radial vessels it is sometimes helpful to supplement an anterolateral longitudinal incision by curving it across a portion of the antecubital space.

One of us used these incisions in 11 aneurysms of the radial and ulnar vessels.² They proved entirely satisfactory. Prompt healing occurred in all, and in none was there any scarring or contractures. The only untoward occurrence was a superficial slough about 1 cm. in diameter in one case in which the corner of an L-shaped incision was perhaps traumatized during operation. The slough, however, did not involve the entire thickness of the skin and epithelization was rapid.

Lesions of the lower portion of the brachial artery and of the upper portion of the radial and ulnar arteries can be approached through an S-shaped incision in the cubital space. Separation of the brachioradialis and pronator teres muscles will expose the radial artery in the upper portion of its course,

² Shumacker, H. B., Jr.: Incisions in surgery of aneurysms, with special reference to exploration in the antecubital and popliteal fossae. *Ann. Surg.* 124: 586-598, Sep 1946.

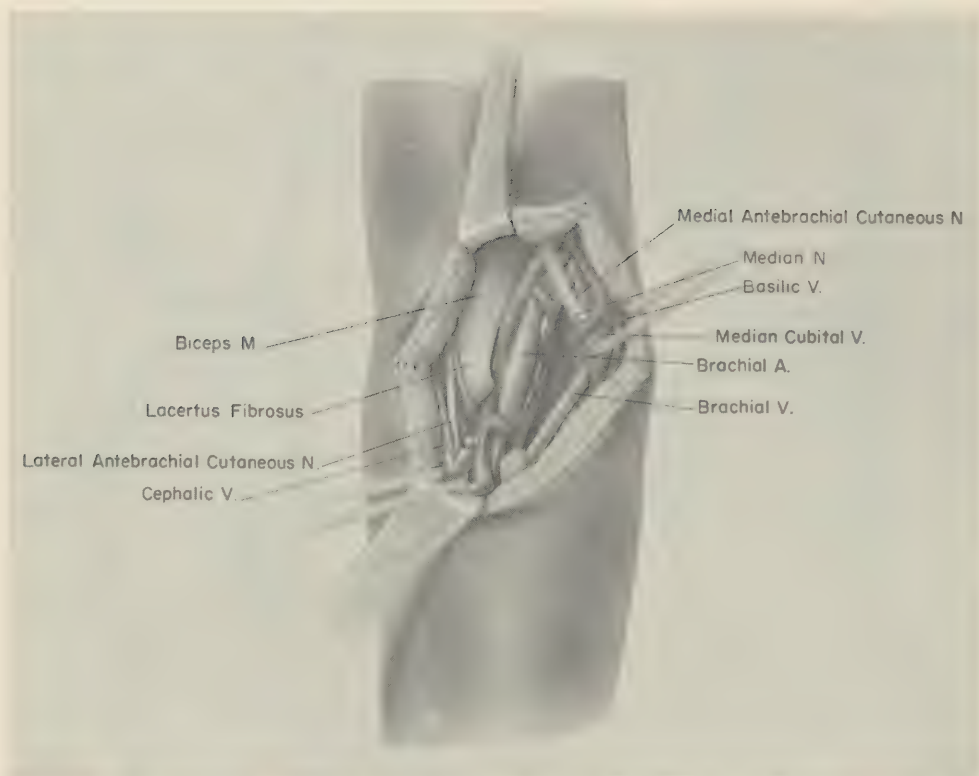


Figure 26. Exposure of fistula between brachial artery and vein in antecubital space. The communications between the basilic and cephalic veins have been divided, and the lacertus fibrosus has been severed. Note exposure of cutaneous and median nerves.

and separation of the flexor carpi ulnaris and the flexor digitorum sublimis will reveal the ulnar artery throughout its course in the forearm.

VESSELS OF THE SCALP

Cirroid aneurysms of the scalp may arise independently or may be preceded by a congenital angiomatic vascular abnormality. Since trauma, frequently inconsequential, may be the starting point, one might expect many of them to follow injury by military missiles. In all, however, only nine aneurysms of this kind were observed at the vascular centers during World War II.

Cirroid aneurysm, which is also known as serpentine or racemose aneurysm, may originate in congenital telangiectases, nevi, or angiomas, particularly if intermediary trauma or long continued irritation has occurred. Multiple communications between vessels may, however, follow trauma in the absence of preexisting vascular lesion. The term cirroid is generally limited to a lesion which is in effect a diffuse arteriovenous fistula formed by multiple anastomoses between contributing arteries and outgoing veins.

The possibility of an intracranial extension of such a lesion or of the extracranial manifestation of a primary intracranial varix must be borne in mind whenever a cirroid aneurysm is encountered.

A variety of methods has been employed in the management of cirroid aneurysms of the scalp, including carotid ligation, ligation of the multiple vessels connected with the lesion, obliteration through galvanocauterization or by the injection of thrombosing solutions, and extirpation. The method last named is undoubtedly more certain of cure and therefore the procedure of choice. It is performed as follows:

As a preliminary step, the principal artery (arteries) leading to the lesion is independently ligated. A horseshoe flap of scalp is turned down to expose the lesion from the underside; care is taken to include the galea in the flap. This step amounts to carrying the incision down to the pericranium and reflecting with the lesion all tissues superficial to it. Hemostasis is obtained by digital pressure and by individual ligation and division of each vessel as it is encountered in the incision. The main vessels, including the central portion of the lesion, are completely excised from the underside of the flap. Particular care is taken not to buttonhole the skin. After excision of the lesion the flap is replaced with interrupted stitches of silk in the galea and in the skin.

Case 1. This 25-year-old soldier sustained an injury to the right parietal region in 1937, when he was struck on the head by a fist during an altercation. Following this a small pulsating hematoma, 0.5 cm. in diameter, developed which gave him no trouble. On 12 March 1945 while in combat training he was accidentally struck on the right side of his scalp by the elbow of his opponent. Three hours later he noticed that the mass was considerably increased in size, although it was neither painful nor tender. Within the next month the swelling increased rapidly and he became conscious of a discomforting pulsation in his scalp, and a throbbing, buzzing sensation in his left ear. He was admitted to Ashford General Hospital on 23 April 1945.

On examination, a large tortuous system of convoluted blood vessels covered the whole right side of his scalp (Fig. 27A). The main tumor mass was centered in the right parietal region and the vessels which radiated to and from it were apparently derived mainly from both superficial temporal, frontal, and the left occipital veins and arteries (Fig. 27B). From the center tumor in the right parietal region vessels radiated over the entire scalp. These appeared to be venous and were readily compressible, although all of them pulsated. Over the right parietal region a harsh, continuous bruit and the thrill could be heard. The bruit was transmitted throughout the scalp but was readily obliterated by pressure of the right carotid vessels in the neck.

Operation was performed on 8 May 1945. Preliminary to excision of the aneurysm the right external carotid artery was ligated and the left occipital and left superficial temporal arteries were ligated and divided. A horseshoe-shaped incision, with its base above the right ear, was then turned downward. The incision was carried through the galea and numerous large tortuous vessels were ligated and divided as they were reached. The galea was then opened and a mass of dilated vessels removed from the underside of the flap. In spite of previous ligations there was considerable bleeding during the operation which was controlled by sutures and coagulation. The flap was replaced by suturing the galea and skin with interrupted sutures of silk.

Recovery was uneventful and 3 months after operation there was no evidence of recurrence. (Fig. 27C and D.)



Figure 27. (Case 1.) A and B show cirroid aneurysm of the scalp condition before operation, 8 May 1945. C. and D. Appearance of head 3 months after operation.

VESSELS IN THE NECK

Although the great vessels of the neck are frequently exposed by longitudinal incisions along their courses, the resulting scars are often heavy and wide and associated with keloid formation and actual contractures. On the other hand, general experience with oblique skin incisions following natural skin creases of the neck has been that scars are inconspicuous and never cause

contractures or deformity. When such incisions are properly placed, exposure of the carotid artery and jugular vein is entirely adequate. Localization of the level of the lesion is usually possible prior to exploration. If this is done, and if the skin incision is properly placed, the whole procedure is simple. The upper and lower skin flaps are widely mobilized, the fascia is incised along the anterior border of the sternocleidomastoid muscle which is retracted posteriorly, and the carotid sheath is opened longitudinally. The vessels above, below, and at the site of the lesion can thus be exposed adequately. The vagus nerve can also be visualized and protected against injury.

Resection of the Clavicle. In the approach to the great vessels at the base of the neck (that is, the subclavian, axillary, carotid, innominate, and their branches), the clavicle frequently prevents adequate exposure and control of the vessels proximal and distal to the vascular lesion. The safety of vascular surgery in this region, however, depends largely upon the accuracy with which isolation of these vessels is accomplished. Removal of a portion of the clavicle is often the solution of the problem. This procedure greatly facilitates all vascular operations at the base of the neck, does not interfere with local motion, produces no noticeable deformity, and leaves no residual pain. During World War II this technique was employed in almost 50 cases at the vascular centers in the Zone of Interior with uniformly good results. Resection of the medial half of the clavicle with its sternal articulation improves the exposure of lesions of the base of the neck and the superior mediastinum. Exposure of the subclavian and axillary vessels requires resection of only the central third of the bone.

Incision is made over the most prominent portion of the clavicle to be resected (Fig. 28) and is extended as necessary along the course of the vessels. When skin flaps are reflected the clavicle, the manubrium, the sternum, and the muscles attached to these structures are readily accessible. Incision of the periosteum on the anterior surface of the clavicle, away from the sites of muscular attachment, greatly reduces the amount of bleeding. The periosteum strips freely in this area, but the transverse scapular vessels run close to the posterior surface of the clavicle and are easily injured if the periosteum is torn. If the clavicle itself forms part of the false sac of an arterial aneurysm, as it not infrequently does, its removal may be accompanied by profuse bleeding which must be controlled at the site of the opening by digital pressure. The mobilized portion of the bone is divided with a Gigli saw. If the sternal end is removed the cartilage should be excised with it.

A vertical incision beneath the sternal end of the clavicle will expose the innominate and carotid vessels and the first portion of the subclavian artery and its branches. The sternum is divided in the midline down to the level of the second interspace and is transected at this level. It is then spread apart with traction upon bone hooks, or is separated with a rib spreader. Either method provides good visualization of the vessels. A vertical incision through the central portion of the clavicular bed will expose the subclavian vessels

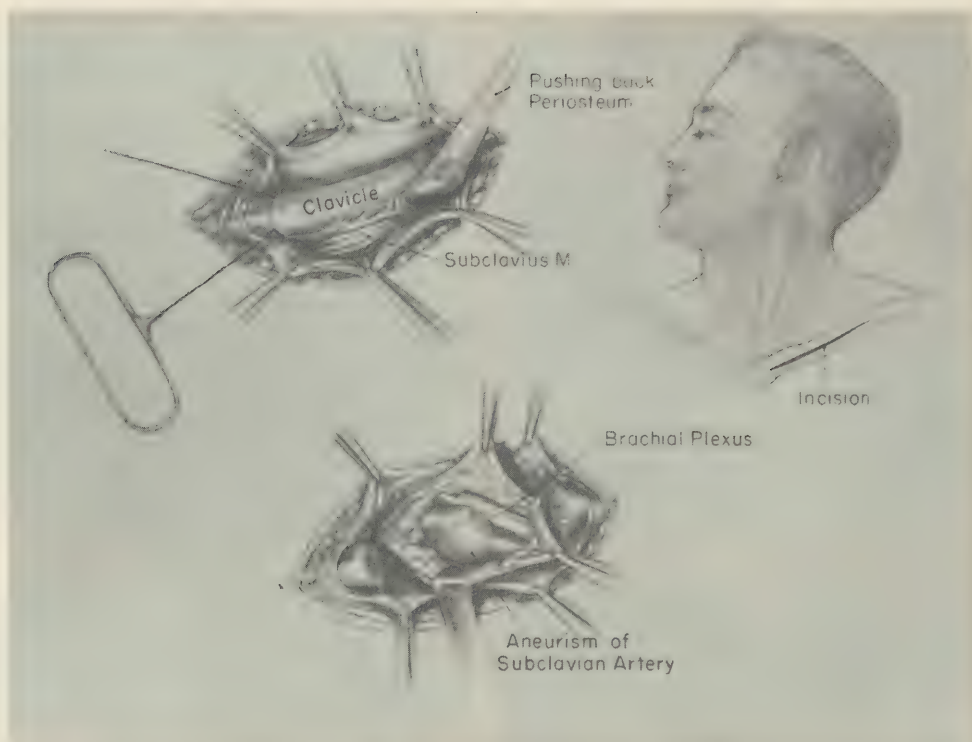


Figure 28. Resection of clavicle subperiostally to expose aneurysm of subclavian artery.

and the brachial plexus. Division of the anterior scalene muscle facilitates exposure of the first and second portions of the subclavian artery. It also facilitates exposure of the vertebral artery and the thyrocervical trunk. Extension of the incision laterally, with the cephalic vein as a landmark, and division of the costocoracoid membrane, reveals the route to the axillary vessels.

Closure of the wound is effected by layers. For the repair of the periosteum, interrupted sutures of fine silk are used.

The resected segment is not replaced. Experience has shown that results are poor if the resected bone is reinserted and fixed in place by approximating it to the remaining bone with wire or other sutures. When this is attempted, proper immobilization is often not secured and painful nonunion or malunion occurs so commonly as to make the procedure eminently unsatisfactory. Other complications such as osteomyelitis and subluxation of the sternoclavicular joint may result. In fact it is sometimes necessary to remove the replaced portion of the clavicle to give the patient relief.

At the conclusion of the operation the dressing is reinforced with adhesive tape, the arm and forearm being left free. The patient is kept in bed for 2

weeks. He is asked to lie flat on his back and to hold his shoulders well back. (No external apparatus to insure immobilization is used.) During the third week he is allowed to move about, but is encouraged to rest a considerable part of the time on his back.

There is little discomfort after this operation, and activity is not associated with pain. The area of the clavicular defect rapidly becomes firm and on clinical examination the absence of the bone cannot be detected, even on careful palpation. There is little external deformity and asymmetry is less than when the resected segment of clavicle is replaced. Resection of the articular portion of the clavicle makes no difference in the postoperative results. The patient returns to normal activity within 6 to 8 weeks.

Although new bone can be palpated in the clavicle within a few weeks of operation, several months must elapse before it can be demonstrated by roentgenogram. During this time, as already mentioned, patients are active and have no discomfort on motion. These results suggest that the concept of the function of the clavicle as a fulcrum to provide better lateral motion of the arm should be revised. The suggestion is supported by the fact that the occasional congenital absence of this bone is known to be of no great consequence, and that in many carnivora it is normally rudimentary.

In a case observed at Mayo General Hospital excessive bony regeneration had occurred at the site where the periosteum of the clavicle had been divided. While the patient had no complaints at time of disposition, it is conceivable, on the analogy with the excessive callus formation which sometimes follows fractures of the clavicle, that pressure upon the brachial plexus might occur later. In view of this possibility the periosteum should be so transected that the incision does not lie over this plexus.

Replacement of the Clavicle by Bone Chips. Although patients who have had the clavicle removed have normal configuration of shoulders, normal motion, and are entirely comfortable, regeneration of the bone is slow and it would be desirable to hasten it if this could be accomplished without undue risk. For this reason, one of us devised the plan of filling the periosteal bed with bone chips secured from the excised bone.³ In the 4 patients in which the method was employed at the vascular center of Mayo General Hospital, the results were excellent.

In each instance the clavicle was excised subperiosteally and care taken to preserve the periosteum intact. In one patient the periosteum was also transected to facilitate exposure. The bone was divided with a Gigli saw. The excised segment was kept in sterile physiologic salt solution until the vascular phase of the operation had been completed, and was then converted into small bone chips, 2 to 3 mm. in diameter, with a rongeur. These chips were packed into the periosteal bed, a sufficient quantity for this purpose being obtained

³ Shumacker, H. B., Jr.: Resection of clavicle with particular reference to use of bone chips in periosteal bed. *Surg., Gynec. & Obst.* 84: 245-248, Feb 1947.

from one-half to two-thirds of the resected bone. The periosteum was closed with interrupted sutures of fine silk.

Postoperative treatment followed the usual regimen after resection of the clavicle. Definite firmness was noted in the region of the excised bone earlier than in patients who had been subjected to similar resections without replacement of bone chips. Osseous regeneration was rapid and complete. Beginning callus formation was evident in 2 patients 3 weeks after operation; complete regeneration was observed in all 4 patients by the 18th postoperative week. Roentgenologic studies in 10 patients in whom the excised bone was not replaced by bone chips showed in most instances no callus formation at periods ranging from 5 to 34 weeks after operation. In these patients, furthermore, regeneration sometimes proceeded from the ends of the remaining bone rather than throughout the periosteal bed, as happened when bone chips were used. In 1 patient eburnation of the bone-ends 34 weeks after operation made it doubtful that union would be achieved at all.

VESSELS WITHIN THE MEDIASTINUM

Reports of the successful treatment of vascular lesions of the vessels which lie within the mediastinum are not common, though almost every conceivable type of operative approach has been employed since Valentine Mott⁴ first ligated the innominate artery in 1818 in an attempt to cure a traumatic subclavian aneurysm. In Greenough's review⁵ of the literature on the subject, published in 1929, the fact is emphasized that safety can be achieved only by adequate resection of the overlying bony framework. In only 37 of the 91 cases of innominate ligation or attempted ligation which Greenough collected was resection, or ostectomy, of the overlying bones performed. Inadequate exposure of the vessels was the primary factor in a number of the 18 fatalities in this group.

Technical Considerations in Exposure of Vessels in the Mediastinum

In Greenough's review of the operations performed upon the innominate artery it is interesting to note the wide variety of procedures employed to expose the vessel. In 11 patients a portion of the clavicle and the manubrium was resected. In 11 others only a part of the clavicle was resected; in 1 patient this procedure was combined with partial resection of the first costal cartilage. Other maneuvers included sternoclavicular disarticulation; splitting of the sternum in the midline; partial excision of the manubrium, clavicle, and first rib; and resection of the manubrium with or without excision of the first two costal cartilages.

⁴ Mott, V.: Reflections on securing in a ligature the arteria innominata, to which is added a case in which this artery was tied by a surgical operation. *Med. and Surg. Register*, New York 1: 9-54, 1818.

⁵ Greenough, J.: Operations on innominate artery; report of successful ligation. *Arch. Surg.* 19: 1484-1544, pt. 2 Dec 1929.

The operation described by Bardenheuer⁶ illustrates exposure by resection of bone. The inner part of the clavicle and first rib are removed on one side and the manubrium is sectioned transversely about an inch below the superior border. The opposite clavicle and the first and second ribs on that side are then divided and the freed manubrium is excised. Various modifications of the procedure have been employed.

Exposure of about the same extent is obtained by the osteoplastic operation of Kocher.⁷ The manubrium is reflected as a flap attached to the costal cartilages on one side after division or disarticulation of the clavicles, the first and second cartilages on one side, and transection of the sternum at the level of the second interspace. The exposure devised by Sauerbruch and Schumacher⁸ for mediastinal explorations has also been used for vascular operations in the mediastinum. It requires splitting of the sternum longitudinally down to the level of the third interspace and cutting it across into this interspace. In spite of the excellent exposure thus secured of the arch of the aorta and the proximal and midportions of the innominate vessels, it is impossible even with wide retraction of the divided sternum to obtain adequate visualization of the subclavian and carotid arteries or of lesions hidden under the upper part of the manubrium and the sternoclavicular joint.

Most textbooks of surgery in discussions of aneurysms and other lesions of the innominate artery describe methods of exposure directed toward ligating that vessel by resection of the clavicle and disarticulation of its medial end. This exposure, however, is inadequate in the presence of an aneurysm or arteriovenous fistula near the aorta in which constant risk of hemorrhage makes adequate exposure particularly imperative. Manipulations must be conducted under full vision because the vessels are dilated and thin-walled. Each case must be considered an individual problem and effort made to choose the ideal operative approach. To illustrate: Within a short period, three cases involving innominate aneurysms and arteriovenous fistulas were reported and in each a different approach was used. One of us resected the inner half of the clavicle, the second costal cartilage and the inner portion of the accompanying rib, divided the manubrium, and excised a portion of its right half.⁹ Trent,¹⁰ after resection of the second rib and cartilage and division of the third, used a transpleural approach. Lindskog¹¹ excised the proximal portion of the second costal cartilage, partially divided the sternum by rongeur at this level, split the manubrium vertically with a Gigli saw introduced from above, and divided the clavicle.

An exposure employed at Mayo General Hospital which proved extremely satisfactory, is carried out as follows: An incision is made from the midportion of the clavicle down over the sternoclavicular joint to the midline. From

⁶ Bardenheuer: Die Resection des Manubrium Sterni. *Deutsche med. Wchnschr.* 11: 688-690, 1885.

⁷ Kocher, Theodor: *Textbook of Operative Surgery*. New York, The Macmillan Co., 1911.

⁸ Sauerbruch, F., and Schumacher, E. D.: *Technik der Thoraxchirurgie*. Berlin, J. Springer, 1911.

⁹ Elkin, D. C.: Arteriovenous aneurysm, the approach to the innominate vessels. *J.A.M.A.* 126: 26-27, Sep 1945.

¹⁰ Trent, J. C.: Ligation of the innominate artery for innominate aneurysm using rubber bands; report of a case. *Surg., Gynec. & Obst.* 82: 463-470, Apr 1946.

¹¹ Lindskog, G. E.: Surgery of the innominate artery. *New England J. Med.* 235: 71-76, Jul 1946.

this point it is continued down over the sternum to the level of the third or fourth interspace. The platysma is divided. The inner third of the clavicle is resected subperiosteally by disarticulation of the sternal end and division of the other end with a Gigli saw. The sternal portion of the sternocleidomastoid muscle is divided, as is a portion of its clavicular origin. The sternohyoid and sternothyroid muscles are similarly severed near their points of origin. It is necessary ordinarily to divide these only on the side on which the clavicle is removed. A finger is gently passed behind the manubrium from above; through this maneuver it is usually possible to separate the manubrium from underlying structures. If a blunt dissector is used for the purpose, dissection must be cautious and under the constant guidance of the palpating finger to avoid trauma to the underlying vessels. The periosteum of the sternum is incised anteriorly in the midline and the sternum split down to the level of the second or third interspace. The Shoemaker sternal shears are ideal for this purpose. The Lebsche knife is less satisfactory, since the bone tends to split in advance of the cut and not always in the midline.

Once the sternum has been divided for some distance its edges can be retracted with bone hooks. Underlying structures can then be palpated satisfactorily and decision made as to whether division of the sternum should be carried out at the second or third interspace to provide the required exposure. The sternum can also be freed more completely from underlying tissues. After complete incision of the periosteum and freeing of the outer borders, the sternum is divided across into both interspaces at the appropriate level. The halves of the divided sternum are now widely retracted. The loose areolar tissue and the remains of the thymus gland are pushed to the side or retracted, and the great vessels thus brought into view (Fig. 29). A small rib spreader is substituted for the bone hooks at this point.

It must be borne in mind in all mediastinal surgery that there is wide variation in the position of the mediastinal structures in relation to the overlying bony framework. The arch of the aorta is occasionally as high as the superior border of the manubrium. The pericardium is sometimes barely in view. The superior vena cava may be of considerable length, while in other cases the innominate veins appear to join more caudally into a short vena cava.

After the necessary vascular surgery is accomplished, the wound is closed in layers. The sternum is reapproximated with wire sutures placed through drill holes or with silk sutures placed in the periosteum. The clavicular periosteal bed is then carefully closed with interrupted silk sutures, or prior to suturing, it may be filled with bone chips from the excised portion of the clavicle to hasten bony repair. The muscles, fascia, and skin are brought together with silk sutures. The skin incision is entirely satisfactory and there is normal range of shoulder motion (Fig. 30) when this technique is used.

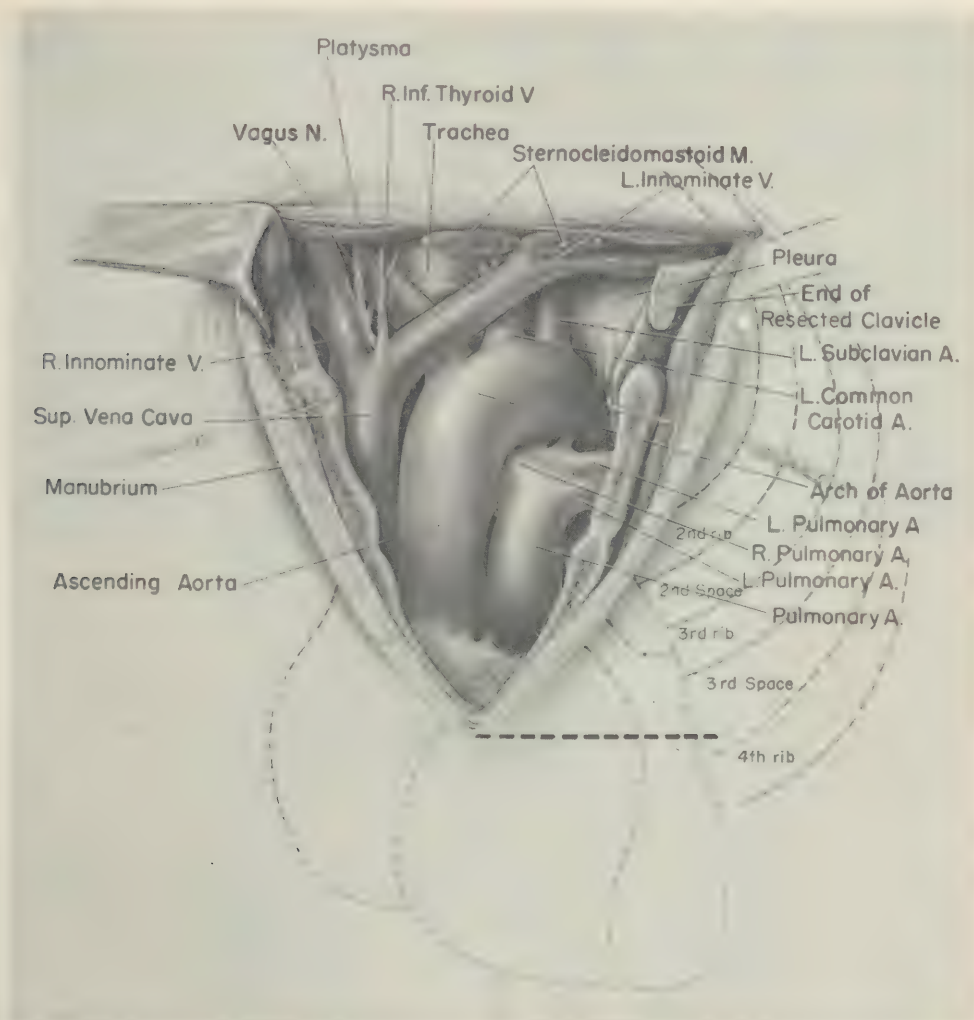


Figure 29. Operative exposure of vessels of superior anterior mediastinum by division of sternum and resection of inner third of left clavicle.

Technical Considerations in Management of Vessels in Mediastinum

In 1945, one of us analyzed 38 reported cases of attempted surgical treatment for innominate aneurysms (36 cases) and arteriovenous fistulas (2 cases).¹² In these, 18 deaths occurred. Thirteen took place among the 20 patients treated prior to 1924, and 4 in the 15 treated after that date (the date was not mentioned in 3 patients reported by Matas, 1 of whom died). Undoubtedly inadequate exposure played an important role in these fatalities. Causes of

¹² Shumacker, H. B., Jr.: Surgical cure of innominate aneurysm. *Surgery* 22: 729-739, Nov 1947.

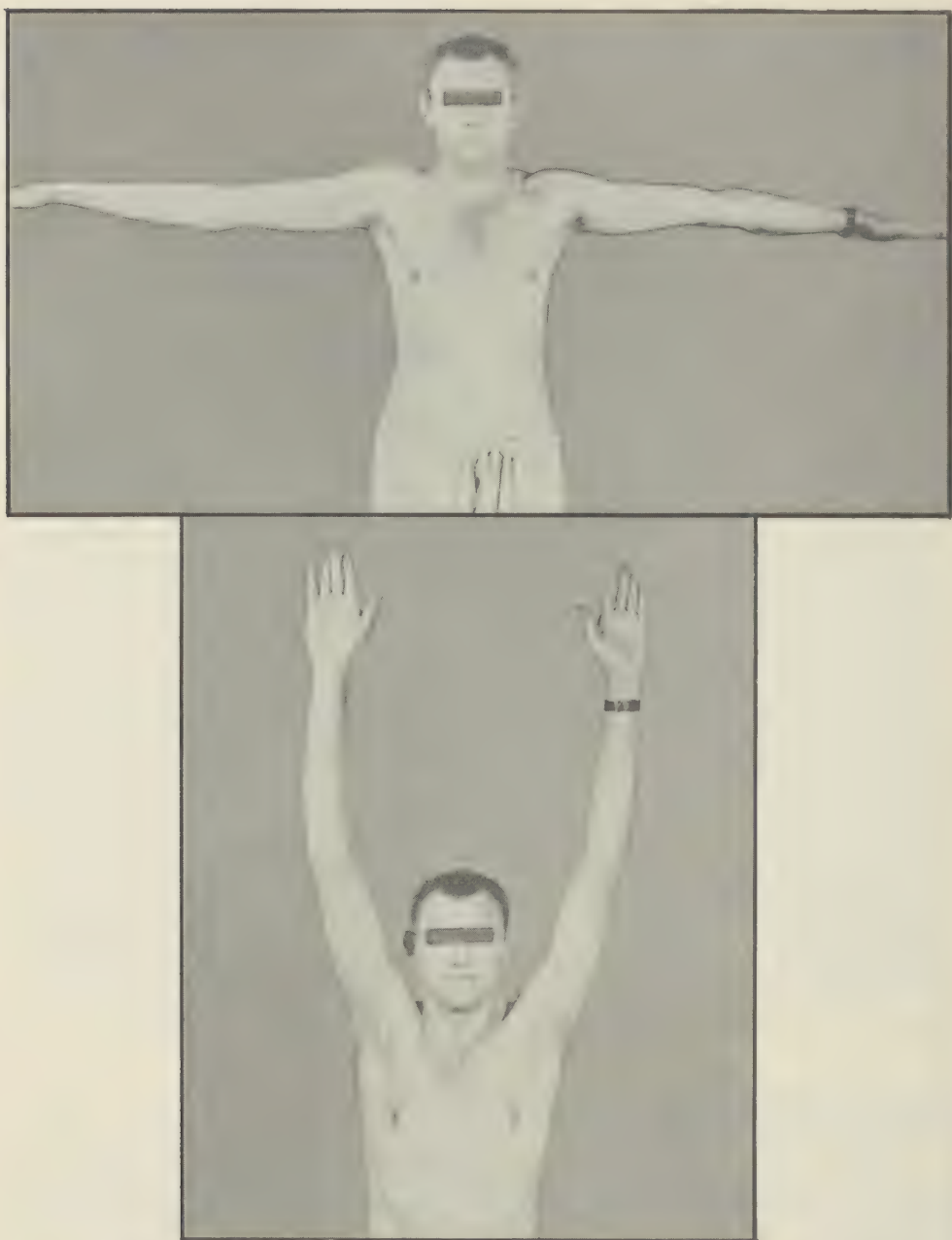


Figure 30. Normal range of shoulder motion in patient submitted to exposure of blood vessels in superior anterior mediastinum by technique shown in Figure 29. In this patient the clavicular periosteal bed was filled with bone chips.

death included tracheal obstruction, uremia, infection, cerebral ischemic difficulties, and hemorrhage and shock. Hemorrhage and shock were reported as causing death in 8 patients and would also seem responsible in 2 or 3 others in which the cause was not given.

With present methods of therapy some of these causes are preventable. Adequate operative exposure, gentle dissection of vessels, and transfusions of whole blood have reduced the hazard of bleeding. Aseptic technique, chemotherapy, and antibiotics have reduced the danger of infection. While cerebral complications are still a danger, this hazard can be reduced to a minimum by repeated preoperative compression of the carotid artery carried out until the patient can tolerate occlusion for a long period. In certain instances it may be advisable, before operation for innominate aneurysms, to perform a preliminary ligation of the carotid artery with a removable metal band, or with a fascial or tape ligature. No instance of gangrene of the upper extremity has been reported after such operations, but other evidences of ischemia have not infrequently been observed. Before permanent ligation the efficacy of the collateral circulation should always be tested by observation of the hand during temporary occlusion of the artery.

There are too few cases in each category of treatment in Shumacker's collected series to permit conclusions about the safety and effectiveness of the various methods. If the artery could be safely and securely repaired, repair would naturally be the method of choice, but it is doubtful that this method can be employed except in occasional cases. It was used in only 1 of the 38 cases collected from the literature and was not practical in any of the cases observed at the vascular centers in World War II. The best procedure from the standpoint of safety to the patient and likelihood of cure of the lesion seems to be proximal and distal ligation (Table 28), combined, when feasible, with excision of the sac, or with evacuation of the thrombus within the sac. Distal ligation will usually involve ligation of the carotid and subclavian arteries. In such cases, as in all instances of arterial surgery, it is wise to divide and transfix the arteries rather than to ligate them in continuity. Opinions differ whether the concomitant vein should be ligated when occlusion of a major artery is necessary.

Of these 38 cases reported up to 1945 only 2 had aneurysms involving the innominate vessel at its point of origin. One of these patients died before ligation could be accomplished; the other, reported by Trent,¹³ survived. Several unreported fatalities have also followed attempts at ligation. Unless constriction with a rubber band, as suggested by Trent, proves the answer to the problem—experience with this method in aneurysms of the aorta suggests that it may end in disaster—some other more indirect method of controlling the aneurysm must be sought. Babcock's surgical production of a carotid-jugular arteriovenous fistula¹⁴ is, according to Matas, a hazardous operation

¹³ See footnote 10, p. 243.

¹⁴ (1) Babcock, W. W.: A new treatment for thoracic aneurysm. *Ann. Clin. Med.* 4: 933-942, 1926.

(2) McCarthy, P. A.: Treatment of aneurysms of thoracic aorta and innominate artery by distal arteriovenous anastomosis. *Ann. Surg.* 91: 161-196, 1930.

TABLE 28. ANALYSIS OF RESULTS OF VARIOUS OPERATIVE PROCEDURES IN PATIENTS WITH INNOMINATE ANEURYSMS AND ARTERIOVENOUS FISTULAS

Procedure	Number of patients	Died	Unimproved	Improved or cured
<i>Arterial aneurysms:</i> ¹				
Attempted ligation.....	5	² 5		
Proximal ligation.....	11	6	1	³ 4
Partial proximal ligation.....	4	1		3
Suture of artery.....	1			1
Ligation of innominate and carotid.....	5	4		1
Ligation of innominate and subclavian.....	3		1	2
Ligation of innominate, carotid, and subclavian.....	7	1		⁴ ⁵ 6
<i>Arteriovenous fistulas:</i>				
Transvenous suture; ligation of vein.....	1	1		
Proximal and distal ligation of artery and distal ligation of vein.....	1			1

¹ Exclusive of preliminary ligations of the carotid and subclavian arteries, 38 operations were performed on 36 patients.

² In 1, carotid and subclavian ligation had been performed 10 months previously.

³ One also had preliminary carotid ligation.

⁴ Following ligation of the innominate, the lesion recurred in 2 patients. At the second operation in 1, the innominate, carotid, and subclavian were ligated and the sac excised. This was followed by cure. At the second operation in the other, the carotid and subclavian were ligated. This was followed by cure, but 8 years later recurrence took place with rupture and death.

⁵ The sac was opened and evacuated, partially excised, and entirely excised in 1 case each.

likely to be followed by functional difficulties.¹⁵ Distal ligation of the carotid and subclavian arteries by the method of Brasdor-Guinard¹⁶ has produced some excellent results¹⁷ but is not generally applicable and the moderate chance of relief offered is quite out of proportion to the gravity of the risk involved.

Wiring combined with coagulation, as developed by Blakemore and King,¹⁸ seems the method of choice when direct surgical intervention on the aneurysm is not feasible. It cannot be considered a curative measure, but is likely to arrest the expansion of the aneurysm and to bring about relief of symptoms. Possibly a combination of wiring and coagulation, with distal ligation of the carotid and subclavian arteries, may yield better results than wiring and coagulation alone. Once the sac wall has been reinforced by an increase in the intramural thrombus following this procedure there should be little hazard associated with distal ligation. After distal ligation there should be a good possibility of obtaining complete saccular thrombosis with further wiring, though this outcome would be impossible with wiring alone.

¹⁵ Matas, R.: On the treatment of aortic aneurysm by method of jugulo-carotid anastomosis; discussion. New Orleans M. & S. J. 84: 445-454, Dec 1931.

¹⁶ Matas, R. In Keen, W. W.: Surgery, Its Principles and Practice. Philadelphia, W. B. Saunders Co., 1920.

¹⁷ (1) Baldwin, J. F.: Aneurysm of the innominate; synchronous ligation of subclavian and common carotid with long survival; unusual incision. Am. J. Surg. 5: 517, Nov 1928.

(2) Schwyzer, A.: Aneurysm of innominate artery. Ann. Surg. 96: 666-669, Oct 1932.

¹⁸ Blakemore, A. H., and King, B. G.: Electrothermic coagulation of aortic aneurysms. J. A. M. A. 111: 1821-1827, Nov 1938.

In view of the limited number of reports in the literature of surgical repair of lesions of the innominate artery, and particularly in view of the small number of successful cases reported, histories of certain of the patients with these lesions observed in the vascular centers in the Zone of Interior in World War II are herewith presented.

Case 2. A 25-year-old soldier was stabbed in the right upper chest with sharp-pointed barber scissors 11 November 1943. He became unconscious from loss of blood and was treated for shock by transfusions of plasma and whole blood. Recovery was prompt and he was returned to full duty in 4 days. When he was reexamined 1 April 1944, a murmur was discovered in the anterior part of the chest. His only complaint was dyspnea on exertion. He was hospitalized at once and subsequently transferred to the vascular center at Ashford General Hospital.

Examination at this center on 6 November 1944 revealed a small healed wound on the anterior wall of the chest just below the right clavicle and 1 inch lateral to the sternal border. In this region could be felt a well-defined continuous thrill, which was less distinct in the neck and along the clavicle. A loud, continuous murmur, intensified in systole, was audible. The bruit was transmitted over the entire anterior part of the chest, both shoulders, and both sides of the neck. It was also heard over the posterior part of the thoracic wall. Neither the thrill nor the bruit could be obliterated by pressure. The blood pressure in the left brachial artery was 135 mm. of mercury systolic and 50 diastolic and in the right 140 mm. of mercury systolic and 40 diastolic. The venous pressure in the left and right cubital veins was 210 and 220 mm. of water respectively. A teleroentgenogram of the heart which had been made 2 October showed a transverse diameter of 16.3 centimeters. After a month of rest a second teleroentgenogram, made a few days after admittance to Ashford, showed that this measurement had decreased to 15.2 centimeters. (Figs. 31A and B.)

Operation was performed 18 January 1945. An incision beginning at the midportion of the clavicle on the right was carried medially to the sternum and downward to the fourth rib. The skin, with the pectoral muscles, was reflected laterally. The inner half of the

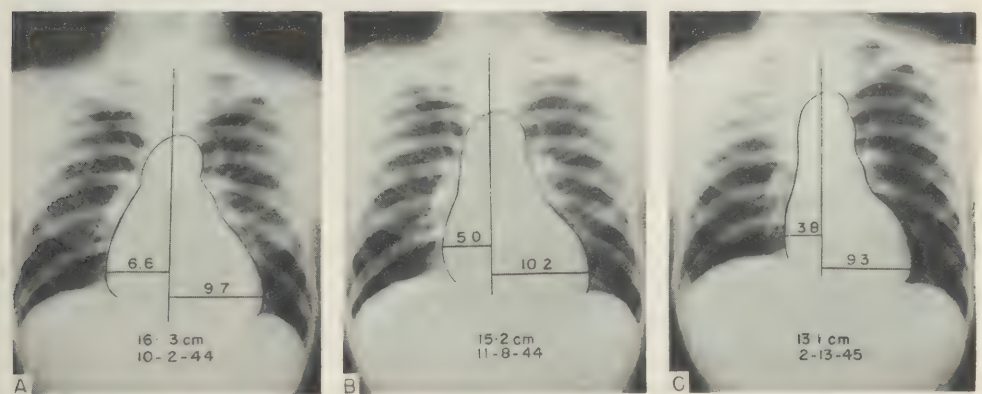


Figure 31. (Case 2.) Roentgenograms showing successive changes in size of heart in traumatic arteriovenous fistula involving innominate vessels. A. Eleven months after injury. B. Twelve months after injury and after 1 month of rest. C. One month after correction of fistula.

clavicle was resected subperiosteally and disarticulated at the sternoclavicular joint (Fig. 32). The second costal cartilage was resected together with about 2 inches of the second rib. The space beneath the manubrium sterni was entered by blunt dissection and the right half of the manubrium divided, its connection with the first rib being left intact. A portion of the right half of the manubrium was removed with a rongeur. The pleura was dissected back by blunt dissection from the midline under the sternum, and the first rib with the attached portion of manubrium was retracted upward and outward. The internal mammary artery and vein, with their branches, were ligated and divided. The regional fat and remains of the thymus gland were removed. The innominate vessels were thus brought into view. After considerable dissection a fistula was found between the innominate artery and the two innominate veins at their point of junction just above the arch of the aorta. Both veins were greatly dilated, as was the artery proximal to the fistula. A false sac had been produced by local dilatation of the veins at the point of the fistula.



Figure 32. (Case 2.) Exposure of innominate vessels for correction of arteriovenous fistula.

A. Removal of portion of clavicle, first and second ribs, and sternum. B. Fistula with false venous sac. C. Transverse section showing false sac and communication between artery and vein. D. Ligation and division of affected vessels.

The right innominate vein distal to the fistula was ligated and divided. The false sac was separated from the aorta to which it was firmly bound, and the innominate artery doubly ligated at its point of origin from the aorta. The thrill and bruit ceased completely when this step of the procedure had been concluded. After ligation of the artery the pulse rate dropped from 84 to 72 beats per minute and the blood pressure rose from 136 mm. of mercury systolic and 60 diastolic to 156 mm. of mercury systolic and 100 diastolic. The innominate artery distal to the fistula was then doubly ligated. It was not thought feasible, however, to ligate the left innominate vein or the superior vena cava. Complete excision

of the fistula was considered, but it would have required ligation and division of both innominate veins, the superior vena cava and the innominate artery, and would have introduced the risk of cerebral edema. The operation was therefore discontinued at this point. Since no branches of the innominate artery communicated with the fistula it was hoped that the communication would be eliminated by what had already been done.

The sternum with the attached first rib was replaced and sutured with tantalum wire. The musculocutaneous flap was replaced with interrupted silk sutures.

At the end of the operation, which required 7 hours, the pulse rate was 68 beats per minute and the blood pressure 140 mm. of mercury systolic and 82 diastolic. The hand and fingers were warm.

Recovery was uneventful except that it was necessary to aspirate collections of blood beneath the pectoral muscles on three occasions. The temperature did not rise above normal at any time during the patient's convalescence and the highest pulse rate was 100 beats per minute. The hand and fingers on the affected side were always warm. Teleoroentgenograms of the heart made on 13 February 1945, 3½ months after last preoperative determination, showed the transverse diameter to be 13.1 cm., a reduction of 2.1 cm. (Fig. 31C). The venous pressure in the cubital veins on the same date was 154 mm. of water on the left and 234 mm. on the right. Hand, arm, and shoulder movements were all within normal range. Examination of the chest 17 May 1945 revealed neither bruit nor thrill and the patient was considered cured.

Case 3. A 35-year-old officer was wounded 19 August 1944 by shell fragments which caused a large avulsed wound of the left thigh and a small wound in the right infraclavicular area near the sternum. When he arrived at a general hospital in the Zone of Interior he complained of a buzzing, throbbing sensation in the right sternoclavicular area, but had noted no other symptoms. Examination revealed an arteriovenous fistula in this area and he was transferred to the vascular center at Mayo General Hospital.

Examination at this center revealed a continuous thrill and murmur, most prominent just below the sternal end of the clavicle. The bruit was transmitted downward toward the heart, outward over the course of the subclavian and axillary vessels, and upward into the neck, though in the latter region it was heard somewhat less clearly. Neither thrill nor bruit could be eliminated by digital compression. There were no evident circulatory changes in the right upper extremity. The electrocardiogram revealed no abnormality. Roentgenograms revealed the presence of a small fragment of metal below the sternoclavicular joint, otherwise they showed nothing informative.

Exploration 16 February 1945 through the incision described in Case 2 revealed a fistula between the internal mammary artery and the overlying innominate vein. The shell fragment was imbedded in the posterior wall of the vein. The vessel was indurated and scarred in this area. The fistula was excised with quadruple ligation of the affected vessels.

Convalescence was uneventful and upon examination 10 months after operation, the patient appeared cured.

Case 4. A 24-year-old soldier was injured by shell fragments 20 October 1944. He received penetrating wounds of the left malar region, the left side of the neck and the left supraclavicular fossa. The shell blast caused temporary loss of consciousness. Shortly after injury he lost his hearing on the left side and became hoarse. He was found to have a fracture of the maxilla and a massive hemothorax. The fracture was reduced through a Caldwell-Luc approach and the hemothorax was treated by thoracentesis. As a result, his hearing began to improve, but a distressing tinnitus and hoarseness persisted. He also developed a throbbing, aching pain in the left arm, and subsequently a persistent left ulnar hypesthesia. Decortication of the left lung was performed and after recovery he was transferred to the vascular center of Mayo General Hospital.

The patient was admitted to this vascular center 9 March 1945 with a diagnosis of left carotid aneurysm. At this time he complained of abnormal pulsation in the left side

of the neck, throbbing pain in the left arm, numbness in the left ulnar area, tinnitus in the left ear, watering in the left eye, and hoarseness.

Examination revealed a pulsating mass at the base of the left side of the neck. No thrill could be demonstrated, but there was a loud systolic bruit. The bruit could be obliterated by digital compression. Pressure over the inner part of the mass interrupted carotid pulsation and reduced the radial pulse. No circulatory disturbance of the left upper extremity was evident, but left ulnar hypesthesia was demonstrable. The patient also presented left recurrent laryngeal paralysis and bilateral deafness of the nerve type. The blood pressure was 116 mm. of mercury systolic and 70 diastolic. Electrocardiograms gave no evidence of abnormality and roentgenograms showed nothing informative. The reactive hyperemia test, with the left subclavian artery occluded, gave evidence of good collateral circulation.

The condition was diagnosed as traumatic aneurysm of the subclavian or the common carotid artery. After repeated digital occlusion of the carotid artery, which was tolerated without symptoms, operation was performed 4 May 1945. A large subclavian aneurysm was found over which the left vagus nerve was stretched. Except that it was thinner than normal the nerve seemed uninjured. The carotid artery was not involved.

The operative approach described in Case 2 was used. The first portion of the subclavian artery was isolated medial and inferior to the sac and a tape placed about it. The subclavian artery was isolated distal to the sac and dissected back toward the involved area beneath the aneurysm. When the artery was occluded proximally and distally the aneurysmal sac, though it ceased to pulsate, continued to fill rapidly with bright arterial blood. This was demonstrated by needle aspiration. Since it was evident that the vertebral artery also opened into the sac, it was feared that simple proximal and distal ligation of the subclavian artery would not effect a cure. The vertebral artery, however, was inaccessible because of the overlying aneurysmal sac and the adjacent scarring. The sac was therefore carefully freed back to its mouth during temporary occlusion of the subclavian artery on either side of the aneurysm, after which it was opened widely. Back bleeding was prevented by digital pressure while the subclavian artery was ligated just proximally and distally. The vertebral artery could then be dissected free and ligated. The sac was totally resected after the overlying innominate, subclavian, and internal jugular veins had been ligated and divided.

The patient was in good condition throughout the procedure, but remained drowsy afterward. There was no paralysis of the extremities. About 8 hours after operation he complained of severe headache. He became first stuporous, then comatose, and death occurred 14 hours after operation. At necropsy extensive encephalomalacia of the left cerebellum was found. No embolus was demonstrated, there was no thrombosis of the left vertebral artery, and the circle of Willis was normal.

Case 5. A 25-year-old soldier was struck in the right suprasternal region by a small shell fragment 14 July 1944. There was no external bleeding, but thoracentesis was required twice because of hemothorax. For a while he progressed satisfactorily, but 9 days after injury when told that he was being returned to duty he became very hoarse and for several days could not speak at all. Four months later, after he had been passed through several replacement centers and hospitals, including a psychiatric installation, a right recurrent laryngeal paralysis and a mass in the anterior mediastinum were discovered. He arrived in the Zone of Interior 10 December 1944.

The patient reached the vascular center of Mayo General Hospital 22 December 1944. By this time he had regained his normal voice, but complained of a constant sense of oppression accentuated by bending forward and localized in the upper anterior part of the chest, also of substernal pain on deep inspiration, and some weakness of the right upper extremity. He stated that this extremity was often darker in color than the left and that the veins of the hand often appeared distended. He attributed a weight loss of some thirty pounds to poor appetite.

Examination revealed a loud systolic bruit in the right supraclavicular fossa. A similar sound was present to a lesser extent in the suprasternal notch and to the right of, and over, the upper sternum. Pulses in the upper extremities were about equal in force. Blood pressure was 134 mm. of mercury systolic and 80 diastolic in the right arm and 146 systolic and 90 diastolic in the left. No color changes were noted in the extremities and sweating was normal, but the veins of the right hand were somewhat distended. In a room at 22° C. the fingers of this hand were from 2 to 5 degrees cooler than those of the left hand. Oscillometric readings revealed that the oscillations were equal in both arms, but slightly less at the right wrist than at the left. Tracings of the ergograph revealed some weakness of the right hand. A traumatic arterial aneurysm with right recurrent laryngeal palsy was suspected. He withstood prolonged right carotid compression repeatedly without difficulty. Laryngoscopic examination showed paralysis of the right vocal cord. Electrocardiograms revealed no abnormality. Roentgenograms demonstrated a mass in the upper right section of the anterior mediastinum (Fig. 33A).



Figure 33. (Case 5.) Roentgenograms showing innominate aneurysm. A. Approximately 5½ months after injury. B. Fifteen days after partial ligation of innominate artery. Note that the aneurysm is unchanged in size. C. Eleven weeks after second operation, at which complete correction of the vascular lesion was accomplished.

Exploration was carried out 15 February 1945 through a sternum-splitting incision. The sternum was divided down to the level of the third interspace and across into the interspace on both sides. This approach permitted the exposure of a large saccular aneurysm of the innominate artery. The lesion originated about 2 cm. distal to the origin of the vessel and involved a considerable portion of its length. When the artery was occluded proximally with a rubber-shod clamp, the right hand immediately became extremely pale and cold, and neither color nor warmth returned during the 15-minute period of occlusion. Because of this observation it was thought unwise to carry out complete ligation. The artery was therefore constricted to about one-half its diameter with a strip of fascia secured with interrupted mattress sutures of silk; over this a band of cellophane was placed. At the conclusion of the procedure the radial pulse was smaller on the right than on the left, and oscillometric studies showed oscillations in the right arm reduced by about 40 percent as compared with the left.

By the 15th postoperative day, oscillometric studies showed that the discrepancy between the two arms had completely disappeared. The bruit in the right side of the chest had, however, increased in intensity and was now the same as at the time of admittance. Roentgenograms revealed no reduction in the size of the aneurysm (Fig. 33B). It was thought possible that the band placed about the artery had given way, but, whatever the

reason, there was no evidence at this time that the artery was partially constricted. In view of the ischemia which had occurred during complete temporary arterial occlusion, it was decided to perform sympathectomy in the hope that it might render the collateral circulation adequate. The operation was performed 9 April, and thereafter the right hand was warmer and had a better color than the left.

The mediastinum was again explored 2 June. At the first operation the proximal artery had been readily accessible, but not the subclavian which lay beneath the retracted right side of the manubrium and the sternoclavicular joint. At the second operation, in order to provide better exposure, division of the sternum was supplemented by resection of the inner third of the right clavicle subperiosteally and by section of the anterior scalene muscle. Exposure by this method revealed that the entire aneurysm, which lay in the right side of the mediastinum, extended 1 cm. above the upper border of the divided manubrium and was about 10 cm long and 6 cm. in diameter. It lay lateral to the artery and was partially covered by the innominate vein.

The subclavian, internal jugular, and innominate veins were divided between transfixing ligatures and the intervening segment removed. Isolation of the proximal artery was difficult because of the scarring in the vicinity of the previous partial arterial ligation. In the process of isolating the artery the sac was torn just at its origin. Bleeding was effectively controlled by digital pressure while a clamp was placed across the innominate artery, and the carotid and subclavian arteries were divided between transfixing ligatures of silk. The proximal innominate artery was then ligated with umbilical tape and transfixed and ligated with silk just distal to the tape. The aneurysm was now completely stilled and there was no bleeding. The sac was opened widely and a large amount of laminated thrombus removed. Fibrin foam was placed in the wound before closure. The sternum was brought together with three wire sutures, and the clavicular periosteal bed, the fascia, and the skin closed with silk sutures. Two pints of whole blood were administered during the operation and the blood pressure did not fall below 130 mm. of mercury systolic.

Two hours after operation a nonpulsatile hematoma appeared in the wound. The wound was opened, the clot evacuated, and the skin sutures replaced after thorough irrigation. Otherwise, the postoperative course was uneventful and the end result was satisfactory in every way except for persistence of slight general weakness and slight fatigability of the right hand. When the patient was separated from service in September 1945 he still had a vocal cord paralysis, though he spoke well. Roentgenograms showed no mass in the area formerly occupied by the aneurysm (Fig. 33C).

Case 6. A 27-year-old soldier received shell-fragment wounds in the right thigh, left buttock, back, and posterior aspect of the neck 28 January 1945. He was evacuated to the Zone of Interior and was admitted to the vascular center of Mayo General Hospital with a diagnosis of right subclavian arteriovenous fistula.

When admitted to the hospital he complained of a buzzing sensation in the right sternoclavicular area, numbness in the right ulnar distribution, and hyperhidrosis of the right hand.

Examination revealed a continuous thrill centered over the sternoclavicular area, and a continuous bruit so loud that it masked all respiratory sounds in the chest. Neither bruit nor thrill could be obliterated by digital compression. In comparison with the left hand, the right hand was cooler and oscillometric studies showed a reduction of oscillations. Blood pressure in the right upper extremity was slightly reduced: 142 mm. of mercury systolic and 76 diastolic. The electrocardiogram revealed no abnormality, and a roentgenogram revealed nothing remarkable except for a metallic foreign body under the sternal end of the right clavicle.

Exploration on 13 June disclosed an arteriovenous fistula between the subclavian artery at its point of origin and the innominate vein at the point at which it received the internal jugular and the two subclavian veins. A large anomalous vein entered the vena cava proximally. The five veins involved could all be ligated without special difficulty.

The subclavian artery was ligated just distal to the fistula as it emerged from the innominate artery; the vertebral and internal mammary arteries, which originated in proximity to the fistulous opening, were also ligated. The distal subclavian artery and veins were divided between transfixing ligatures and part of the venous sac excised.

Convalescence was uneventful. Excellent circulation in the right upper extremity was maintained.

Case 7. A 24-year-old soldier sustained shell-fragment wounds of the abdomen, chest, hands, right forearm and arm, and right leg 24 January 1945. These were debrided, an exploratory laparotomy performed, and numerous thoracenteses done for bilateral hemothorax. Upon the diagnosis of an arteriovenous fistula he was evacuated to the vascular center of Mayo General Hospital, arriving there 21 May 1945.

Examination revealed a continuous murmur audible over the upper anterior part of the chest and maximal over the right border of the sternum at the level of the second interspace. No thrill was palpable. There were no circulatory disturbances of the extremities. Blood pressure was 124 mm. of mercury systolic and 60 diastolic. Electrocardiograms showed nothing abnormal. Roentgenograms of the chest revealed a mass in the upper anterior mediastinum. The impression was that the condition was an arteriovenous and saccular aneurysm, probably involving the innominate vessels.

It was impossible to close the fistula by compression and thus test the collateral circulation to the right upper extremity. The patient, however, tolerated carotid compression without symptoms. Dorsal sympathectomy was performed 5 July and followed by mediastinal exploration 17 September through an approach as described in Case 2.

The upper portion of the mediastinum was found to be filled with a firm, pulsating aneurysmal mass about 7 by 6 cm. in size. Associated with this was a continuous thrill. The carotid and subclavian arteries and the internal jugular veins could be identified at the upper pole of the mass on each side; they appeared to emerge from the aneurysm itself.

The superior vena cava was free proximally but disappeared into the mass about 2 cm. from its cardiac end. The superior border of the arch of the aorta was fused with, and partly buried beneath, the mass. Apparently the arteriovenous and saccular aneurysm involved the innominate vessels, the origins of both carotid and subclavian arteries, the terminal portions of the internal jugular veins, the superior vena cava, and possibly the arch of the aorta. Since surgical extirpation was obviously impossible the wound was closed at once.

Convalescence was uncomplicated and the patient after his recovery was able to do light work about a farm.

Case 8. A 24-year-old soldier was injured in the left thigh, leg, arm, and scapular area by shell fragments 10 December 1944. A femoral fracture and a compound fracture of the tibia and fibula were incurred. Following debridement of the wounds, the left upper and lower extremities were placed in plaster casts. Soon after injury an arteriovenous fistula in the left sternoclavicular region was found and the patient evacuated to the vascular center of Mayo General Hospital. He arrived at this center in May of 1945.

Examination disclosed that the femoral fracture had progressed satisfactorily, but that osteomyelitis had developed following the compound fracture of the tibia and fibula. The patient had no complaints referable to the fistula, but left ulnar paralysis was present and he complained of weakness of the left upper extremity. A continuous thrill was palpable and a loud continuous bruit was heard over the left anterior chest wall and the left side of the neck, most prominently in the sternoclavicular region. Neither bruit nor thrill could be obliterated by digital compression. The fingers on the left hand were cooler than on the right, and pulses and oscillometric readings presented evidence of reduced circulation in the left upper extremity as compared with the right. After treatment on the orthopedic service and left ulnar neurorrhaphy, dorsal sympathectomy was performed 30 August because of the evidence of reduced circulation in the left upper extremity and the impossibility of testing the collateral circulation.

A preoperative diagnosis of arteriovenous fistula of the proximal portion of the subclavian vessels was made, and on 16 September mediastinal exploration was undertaken. A fistula was found between the subclavian artery just distal to the vertebral branch, and the innominate vein near its distal end. After the vessels had been isolated proximally and distally and the fistula dissected free and transfixed, it was discovered that there was also present a saccular aneurysm arising from the posterior surface of the artery opposite the fistulous opening. The artery was badly damaged over a considerable distance. It was therefore ligated on either side of the aneurysm. The innominate, internal jugular, subclavian, and internal mammary veins were divided and the aneurysm and fistula excised.

After an uneventful convalescence the patient was returned to the orthopedic service for further treatment for osteomyelitis.

VERTEBRAL VESSELS

During World War II, 13 arteriovenous fistulas of the vertebral vessels were observed at the vascular centers in the Zone of Interior. This was an unusual experience. The collected reviews of Matas in 1893,¹⁹ of Perrig in 1932,²⁰ and of Heifetz in 1945,²¹ indicate that up to the date last named only 67 instances of this type of aneurysm had been recorded in the literature. The differentiation between arteriovenous fistulas and false arterial aneurysms is not brought out in all of these cases, but it seems clear that the great majority were aneurysms. Arteriovenous fistulas involving the vertebral artery therefore seem to be among the most uncommon of arterial injuries, probably because of the protection afforded by the peculiar anatomic location of that vessel. The outcome is also not clear in all reported cases, but apparently more than half of the patients died as the direct or indirect result of the vascular condition. This is a much higher death rate than is associated with aneurysms or arteriovenous fistulas in almost any other location, and the explanation, again, seems to be the anatomic position of the vessels, with the resulting difficulties at operation.

Diagnosis of aneurysms and fistulas of the vertebral vessels is difficult to make. It was made with certainty in only 5 of the 13 patients observed at the vascular centers in World War II, though suspected in others. The most common erroneous diagnosis is a fistula between the internal jugular vein and the branches of the external carotid artery. Vertebral arterial lesions may also be confused with fistulas arising from other branches of the subclavian artery, particularly the inferior thyroid, transverse scapular, and transverse cervical vessels. Differentiation can usually be made on the basis of whether or not the bruit disappears on compression of the common carotid artery. If it does not, the vertebral vessels should be suspected as the site of the lesion: They lie deep in the neck, and obliteration of the bruit by pressure is difficult although not impossible.

¹⁹ Matas, R.: Traumatism and traumatic aneurysms of the vertebral artery and their surgical treatment; report of a cured case. *Ann. Surg.* 18: 477-521, 1893.

²⁰ Perrig, H.: Zur Anatomie, Klinik und Therapie der Verletzungen und Aneurysmen der Arteria Vertebralis. *Beitr. z. Klin. Chir.* 154: 272-307, 1931.

²¹ Heifetz, C. J.: Traumatic aneurysm of first portion of left vertebral artery; case report. *Ann. Surg.* 122: 102-110, Jul 1945.

At operation, confirmation of the diagnosis of vertebral arteriovenous fistula can usually be made by a process of exclusion. When the other vessels in the neck are isolated and temporarily occluded without effect on the thrill and bruit, the chances are that the vertebral artery is involved. Occasionally, however, collateral circulation is so ample that the bruit persists even during proximal occlusion of the vertebral artery and vein.

Technical Considerations in Exposure of Vertebral Vessels

To comprehend the difficulties in exposing the vertebral artery, a discussion of its anatomic location is necessary. The extracranial portion of the artery is divided, for descriptive purposes, into three parts:

The first (extraforaminal) portion is about 3 cm. long. It arises from the subclavian artery and ascends, on each side of the neck, to the lowermost foramen in the transverse process usually of the sixth cervical vertebra. This part of the vessel runs upward and backward between the longus colli and the anterior scalene muscles. Between it are the transverse process of the seventh cervical vertebra and the sympathetic chain. In front are the vagus nerve, the internal jugular vein, and the sternomastoid muscle which lies in front of the internal jugular vein. The upper portion of the first part of the vertebral artery is crossed by the inferior thyroid artery as it passes medially. It does not enter the foramen in the transverse process of the seventh cervical vertebra, but lies in front of it.

The second portion of the vertebral artery passes upward through the transverse processes of the upper six cervical vertebrae. In this part of its course it lies anterior to the cervical nerves and inferior to the anterior scalene muscle. It is surrounded by a venous complex which terminates below in the vertebral vein. Overlying this part of the artery and slightly to its medial side is the internal jugular vein and, more superficially, the sternomastoid muscle. In the upper part of the second portion of the vertebral artery the spinal accessory nerve is found about 2 fingerbreadths below the mastoid process. Underneath the sternomastoid muscle the dense prevertebral fascia covers the levator scapulae muscle which arises from the transverse process of the upper four cervical vertebrae and therefore directly overlies the vertebral vessels in their course through the upper four foramina.

The third portion of the vertebral artery begins at the point at which it emerges from the foramen of the atlas. It turns backward and lies in a groove on the upper surface of the atlas where it is covered by the semispinalis capitis in the suboccipital triangle. The guide to the artery in this portion of its course is the transverse process of the atlas which can easily be palpated 1 fingerbreadth below, and 1 fingerbreadth in front of, the tip of the mastoid bone. The vessel is more easily identified when the sternomastoid muscle is detached from its origin.

Approach to any portion of the vertebral vessels is difficult because of the deep position and the vital nature of the surrounding structures. Approach to

each portion, moreover, must be considered separately because the anatomy of each portion varies.

In the first portion, exposure is best achieved through an incision parallel with the fibers of the sternomastoid muscle directly over the interval between the sternal and clavicular heads of that muscle. After incision of the deep fascia, the heads of the muscle are separated and retracted (Fig. 34). Some of the fibers may be divided transversely if better exposure is necessary. The internal jugular vein, when it is encountered in the depth of the incision, is retracted medially and the triangular interval between the longus colli and the anterior scalene muscles is developed. The inferior thyroid artery, which will be found running upward and medially and crossing in front of the vertebral artery in this region, must be carefully isolated. The vertebral artery arises medial to the inferior thyroid artery and can be identified in this location by its pulsation. The vertebral vein lies anterior to the artery, and on the left the thoracic duct passes in front of it. This portion of the vertebral artery must always be identified as a preliminary to operations on the vessel anywhere in its course. A ligature passed around it, but left untied, is a protection against hemorrhage later in the operation, though it will only diminish bleeding, not control it, because of the rich anastomotic blood supply in the vertebral system. Ligation of the artery should not be done at this point in the operation since the thrill and bruit would thus be obliterated and identification of the fistula thus become more difficult.

The second portion of the vertebral artery is reached by an incision along the anterior border of the sternomastoid muscle. After the deep fascia is opened the muscle is retracted laterally and the carotid sheath identified and retracted medially. It is usually necessary to divide the omohyoid muscle as it passes across the carotid sheath. The anterior scalene muscle, which arises from the transverse processes of the third, fourth, fifth, and sixth cervical vertebrae, is retracted laterally and may be detached from its origin in order to expose fully the transverse processes through which the vertebral vessels pass. The interval between the transverse processes is less than a finger-breadth, which makes ligation in this region particularly difficult unless one (or more) of the transverse processes is removed with a rongeur. If this is done a ligature may be passed about the vessel preferably on an aneurysm needle, or the vessel may be occluded by the use of heavy metal clips.

Exposure of the upper portion of the second part and of the third part of the vertebral vessels is much more difficult than exposure of the other portions. The technique suggested by Henry²² is most satisfactory. The patient lies on his back with his neck extended and his chin turned to the side opposite the involved vessels. An incision is made along the anterior border of the sternomastoid muscle from the middle of the neck to the mastoid process. The deep fascia is opened. The insertion of the sternomastoid muscle is cut away

²² See footnote 1, p. 230.

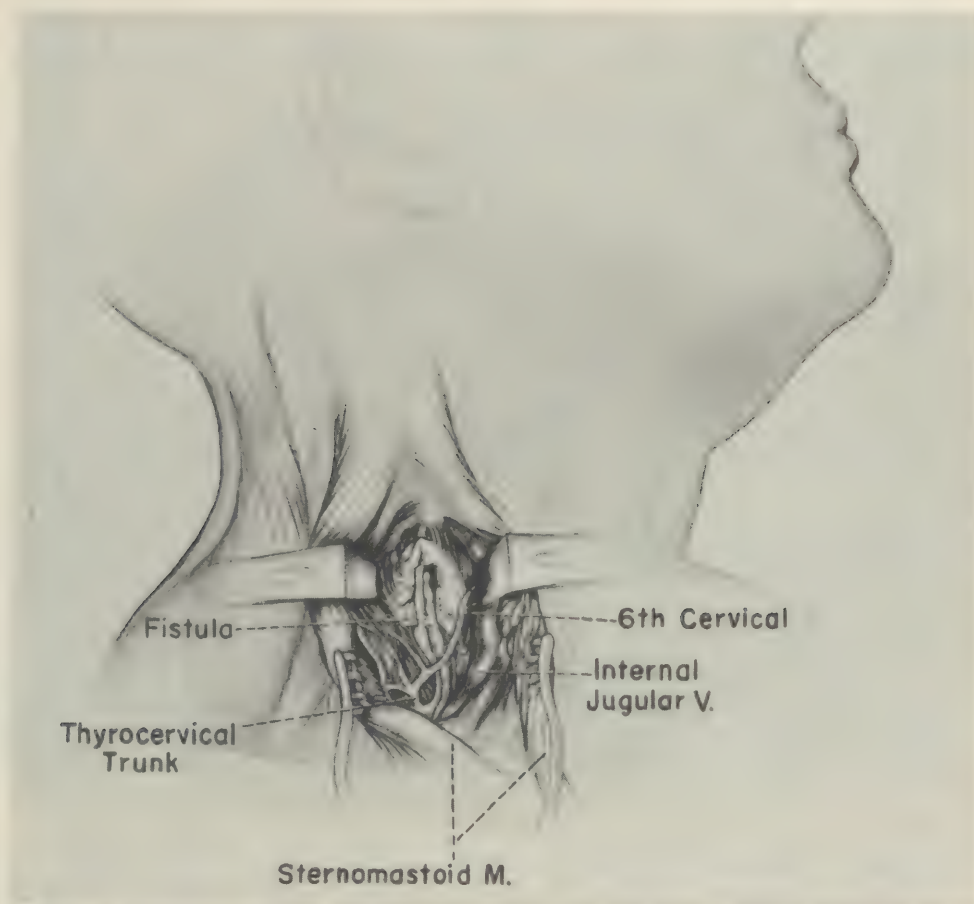


Figure 34. Surgical approach to a fistula between lower portions of the right vertebral vessels.

from the bone and the muscle reflected laterally. The spinal accessory nerve is isolated and mobilized as it passes laterally and downward beneath the sternomastoid muscle (Fig. 35). Once the sternomastoid muscle is reflected, the tip of the transverse process of the atlas is easily identified. The pre-vertebral fascia is divided from above downward, the origin of the levator scapulae muscle cut away from the atlas and axis, and turned downward. Further dissection exposes the vertebral artery and surrounding venous plexus in the interval between the atlas and axis, as well as in its third portion.

Whenever necessary, the transverse processes of the cervical vertebrae should be removed in order to expose completely the lesion and its contributing vessels. If the lesion is close to the origin of the vessels from the subclavian artery, resection of the inner third of the clavicle facilitates control of the blood supply. This is a useful step when the lesion is in the intraforaminal portion of



Figure 35. Surgical approach to a fistula between upper portions of the left vertebral vessels.

the artery. Before it is carried out, however, the slips of the scalene, the longus colli, and longus capitis muscles which are attached to the transverse processes must be stripped away by sharp dissection and the use of a periosteal elevator. In three cases observed at the vascular centers the overlying transverse processes could be removed without injury to the underlying vessels by gently depressing the vessels during the excision of the bony processes with a small rongeur.

If there is difficulty in controlling the spinal branches, the branches can be isolated and either ligated with silk or clipped with silver clips. When this is not possible, bleeding can be controlled by packing with muscle or fibrin foam.

Technical Considerations in Management of Vessels

There was no evidence of cerebral circulatory difficulties in any of the cases observed at the vascular centers. All of the patients had practiced prolonged carotid compression before operation and could withstand it for practically half an hour without symptoms. The abundant collateral circulation about the vertebral vessels in the neck and the communication in the circle of Willis would lead one to assume that cerebral ischemia would not usually follow ligation. One of us, however, observed a case in which aneurysmorrhaphy of a

large subclavian aneurysm required ligation of a single vertebral artery, but of no other vessel supplying the brain.²³ The patient died within 24 hours, and necropsy revealed homolateral cerebellar necrosis without evidence of thrombosis or embolism.

In the 13 patients with vertebral arteriovenous fistula treated in the vascular centers of the Zone of Interior in World War II, the lesion was known to be located in the first portion of the vessel in 2 patients, in the second portion in 6, and in the third portion in 3. No attempt was made in any instance to repair the fistula. The position of the vessels as well as their small size precluded the effort. Anatomic reasons prevented actual excision of the fistula except in 7 instances, and obliteration of the fistula was therefore usually accomplished by proximal and distal ligation of the vessels and by the placing of mass ligatures.

Since arteriovenous fistulas involving the vertebral artery are so rare, three case reports from the experience at Ashford General Hospital are herewith presented.

Case 9. On 28 June 1944, a soldier was struck in the right arm and neck by multiple fragments of an artillery shell. There was profuse bleeding from all wounds. The neck wound was debrided and healed promptly. Approximately 3 weeks later he noted a buzzing sensation in the left side of the neck, but did not hear any noise. He reported this to his medical officer who made a diagnosis of arteriovenous fistula. On admittance to the vascular center of Ashford General Hospital 5 months later, examination revealed that there was a small scar overlying the upper portion of the left sternomastoid muscle about 4 cm. below the angle of the mandible. There was a continuous bruit and thrill heard and felt over this area which were transmitted up the scalp to the parietal region and into the neck to the clavicle. Deep pressure failed to obliterate the bruit and thrill. It was thought that this was an arteriovenous fistula of the second portion of the left vertebral vessels.

On 30 December 1944, the first portion of the vertebral artery was ligated and divided. This caused the thrill and bruit to be almost completely obliterated. On 3 February 1945, an incision was made from the level of the thyroid cartilage upward along the anterior border of the sternomastoid muscle to the mastoid process and then turned backward severing the sternomastoid from the skull at its insertion. The muscle was retracted laterally and the third cervical nerve and the spinal accessory nerve isolated. The levator scapulae muscle was detached from its origin from the atlas, axis, and third and fourth cervical vertebrae. The vertebral vessels were then isolated between the transverse processes of the atlas and axis. The sensory branch of the second cervical nerve overlying the vessels was dissected free and the vertebral artery divided between ligatures. Several smaller vessels in this region were also ligated. The vein was not ligated. This stopped the thrill, but a bruit was still present. As time passed the bruit increased in intensity.

On 25 April 1945, the scar on the left side of the neck was excised and the sternomastoid muscle retracted laterally. The transverse processes of the first, second, third, and fourth vertebrae were exposed. The levator scapulae muscle was detached from the transverse process of the atlas and the spinalis group of muscles freed from the transverse processes of the exposed vertebrae by sharp and blunt dissection. The lateral roofs of the foramina transversarium of the third and fourth cervical vertebrae were removed by rongeur. This exposed the vertebral vessels for a distance of 4 or 5 centimeters. The fistula was apparently

²³ Shumacker, H. B., Jr.: Arteriovenous fistulas of the cervical portion of the vertebral vessels. *Surg., Gynec. & Obst.* 83: 625-630, Nov 1946.

at the level of the inferior border of the canal of the third vertebra. Ligatures were passed about the vessels proximal and distal to the fistula, and the vessels ligated. Silver clips were applied above and below the fistula. This caused the bruit and thrill to disappear completely.

At the time of discharge 3 months later there had been no recurrence of the bruit or thrill.

Case 10. A soldier was wounded in July 1944 by fragments of a high explosive shell. There was a wound below and behind the right mastoid process and one on the back of the right hand. He was unconscious for 15 minutes and bled profusely from the neck wound. The wounds were debrided and he was returned to England where the fragment was removed from the right hand. Forty-three days after injury he was returned to combat duty. Four months later he was evacuated because of combat exhaustion. Upon routine physical examination the presence of an aneurysm of the right side of the neck was discovered and he was returned to the United States.

The patient was admitted to the vascular center of Ashford General Hospital 21 November 1945. His only complaint at that time was of a buzzing sensation in his right ear when lying on that side. Examination revealed a healed wound just posterior to the upper third of the right sternomastoid muscle. In this region a thrill was felt and a continuous bruit heard. The bruit was transmitted throughout the neck, upward behind the ear. It was easily obliterated by pressure over the right common carotid artery. Upon obliteration of the fistula the pulse fell from 80 to 72 beats per minute and the blood pressure rose from 120 mm. of mercury systolic and 68 diastolic to 120 systolic and 80 diastolic. A diagnosis of arteriovenous fistula of the internal carotid artery and internal jugular vein was made.

On 8 December 1945, an incision was made parallel to the anterior border of the right sternomastoid muscle. Since it was thought that the fistula involved the internal carotid artery, the carotid vessels were identified at their bifurcation and ligatures passed about the common, internal, and external carotid arteries. Occlusion of these vessels singly or in combination did not diminish the bruit. Compression at a slightly lower level in the neck obliterated the thrill. Dissection was carried out inferiorly and the vertebral artery identified. It was found that occlusion of this vessel stopped the bruit and thrill. Ligatures were passed about the vertebral vessels. The incision was then extended upward with detachment of the sternomastoid, longus colli, splenius capitis, and levator scapulae muscles from their origins. In this manner the transverse processes of the upper two cervical vertebrae were exposed. The transverse processes of the second cervical vertebra were removed and a ligature passed about the vertebral vessels at this point. Occlusion of the vessels did not result in cessation of the thrill. The third transverse process was similarly removed with isolation of the vessels at the level of the third cervical vertebra. Compression at this point resulted in cessation of the thrill. The vertebral vessels were then ligated at the site of the second and third transverse processes. A mass ligature was tied in the interval between these sutures with further obliteration of a segment of vessel. Slight bleeding was encountered at this time due to the tearing of small branches of the vertebral artery. Further to insure occlusion, a tantalum clip was applied at the site of the fistula. The vertebral artery was doubly ligated in its first portion and a tantalum clip applied at the point at which it entered the sixth vertebra.

Recovery was uneventful. There was no recurrence of the bruit. At the time of the patient's discharge 2 months later, there was no evidence of recurrence of the fistula.

Case 11. A soldier was wounded in action 18 December 1944, when he was struck in the left side of the neck by a shell fragment. The wound of entrance was just inferior and posterior to the angle of the mandible. There was no wound of exit. There was no excessive bleeding and no loss of consciousness. The wound was allowed to heal by second intention. There was marked diminution in the hearing of the left ear after the injury, and he was conscious of a continuous buzzing in that ear. He was evacuated to the United

States and admitted to the vascular center of Ashford General Hospital 8 November 1945. Examination revealed a scar about 1 cm. in diameter just inferior and posterior to the angle of the left mandible. There was a small sinus in the region of this scar from which a limited amount of serous fluid could be expressed. A continuous bruit transmitted to the base of the neck, was heard over this region. It could not be obliterated by occlusion of the common carotid artery or by pressure anywhere in the neck. A diagnosis of vertebral arteriovenous fistula was made.

On 31 January 1946, a 6-cm. transverse incision was made above the medial end of the left clavicle. The two heads of the sternomastoid muscle were separated and the vertebral artery isolated near its origin from the subclavian. Occlusion of this artery did not obliterate the bruit, however it did diminish it. This wound was covered, and a 10-cm. longitudinal incision was made along the medial edge of the sternomastoid muscle extending from the level of the thyroid cartilage upward to the mastoid process, then curved laterally over the mastoid process so that the sternomastoid muscle was detached at its insertion. The spinal accessory nerve was isolated and the sternomastoid muscle reflected outward and downward. The splenius capitis muscle was reflected downward from the transverse process of the atlas. This exposed the vertebral vessels between the axis and atlas. Compression of the vessels in this region did not obliterate the bruit, although it did diminish it. It was then felt that the fistula involved the third portion of the vertebral vessel. The rectus capitis muscle was detached from its origin to the transverse processes of the atlas and axis and reflected downward. This exposed only approximately 2 cm. of the third portion of the vessels. It was therefore necessary to remove the transverse process of the atlas in order to expose adequately the third portion of the vessels. The vessels were then mass ligated distally and proximally to the fistula with two ligatures which were passed about the vessels. This caused the thrill to disappear completely, but the bruit was still slightly audible. It was assumed that there were branches between the proximal and distal ligatures. Three other sutures were passed about the vessels between the proximal and distal ligatures and this caused the bruit to disappear completely. The vessels were not divided. The divided muscles were approximated with interrupted silk sutures.

The postoperative course was uneventful. There was no evidence of recurrence of the bruit or thrill 2 months after operation.

THE ILIAC VESSELS

Approach to the iliac vessels is through a retroperitoneal incision. The peritoneum and abdominal contents are displaced medially to obtain exposure of the ureter in its lower portion. Lesions of the distal external iliac vessels are approached through an oblique incision just above Poupart's ligament. The fascia of the external oblique muscle is divided and the external ring opened. The internal oblique muscle and the transversalis fascia are divided in the direction of their fibers. The iliac vessels are then readily exposed above the inguinal ligament, and the femoral vessels can be exposed below the ligament, if necessary. If exposure is inadequate, the inguinal ligament can be transected to obtain more complete exposure and resutured at the close of the procedure. Closure of the wound is carried out as in herniorrhaphy.

CHAPTER VIII

Arterial Aneurysms and Arteriovenous Fistulas Maintenance of Arterial Continuity

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Though the principles which underlie vascular repair, the precautions which must be observed, the hazards entailed, and the methods applicable, have since been established by experimental investigations upon laboratory animals, actually the first closure of an arterial defect was carried out upon man.¹ Indeed this lateral closure was performed some 125 years before another successful instance of arterial repair in man or experimental animal was accomplished. Dozens of workers contributed to the evolution of the reparative techniques now employed, but Carrel's beautifully planned and executed experiments² perhaps served more than any other investigation to revive and maintain interest in the use of these measures in the management of both arterial aneurysms and arteriovenous fistulas.

The first clinical application of the principles of arterial repair seems to have been made in 1759 when Hallowell, acting on Lambert's suggestion,³ closed a small wound of the brachial artery by placing a pin through the margins, elevating the lacerated area, and twisting a thread about the pin. The next reported successful arterial repair in man was performed in 1886 by Postempski,⁴ who, by lateral arteriorrhaphy, repaired a rent in the femoral artery which he had made accidentally while draining an abscess. By 1903 Höpfner⁵ was able to collect from the literature reports of 30 successful operations in which reparative techniques had been used.

In 1888 Matas⁶ introduced endoaneurysmorrhaphy, a method of intrasac-
cular suture. This technique was first applied "while operating upon a traumatic brachial aneurysm which had resisted proximal and distal ligation." It was subsequently systematized as a method and carried out also in other

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¹ Lambert, R.: Wound of artery treated by pin suture. *Med. Obs. Soc. Phys.*, London, 1762, vol 2, p. 360-364.

² Carrel, A.: Surgery of blood vessels. *Bull. Johns Hopkins Hosp.* 18: 18-28, Jan 1907.

³ See footnote 1, above.

⁴ Postempski, P.: La sutura dei vasi sanguigni. *Arch. Soc. Ital. chir.* Roma 3: 391-395, Apr 1886.

⁵ Höpfner, E.: Über Gefäßnaht, Gefäßstransplantationen und Replantation von amputierten Extremitäten. *Arch. f. klin. Chir.* 70: 417-471, 1903.

⁶ Matas, R.: Traumatic aneurysm of the left brachial artery; . . . incision and partial excision of sac; recovery. *Phila. Med. News* 53: 462-466, Oct 1888.

cases of popliteal and femoral aneurysms. In 1903 Matas⁷ recommended restoration of the circulation through the damaged artery as the ideal treatment for arterial aneurysms. In the following year Bickham⁸ suggested that the Matas endoaneurysmorrhaphy be employed for the intravascular repair of arteriovenous fistulas and recommended transvenous closure of the defects in the vascular walls as a practical method of preserving the continuity of both artery and vein.

The first end-to-end arterial suture in man was reported by Murphy⁹ in 1897. The lesion was a traumatic arteriovenous fistula. He closed the wound of the vein, resected the damaged portion of the artery, and accomplished a successful end-to-end anastomosis by invaginating the proximal into the distal segment. In the same year Djemil-Pascha¹⁰ also reported two successful cases in which this technique was used. Although the first end-to-end arterial sutures in man were performed by the invagination method devised by Murphy, it subsequently became apparent that direct approximation of the divided ends of the artery was a superior method.

In 1906, shortly after Carrel¹¹ and his associates had demonstrated the possibility of arterial repair by transplantation of a vein, Goyanes¹² treated a syphilitic popliteal aneurysm by proximal and distal ligation and then re-established the blood flow by anastomosing the femoral artery to the distal end of the divided femoral vein and the proximal end of the divided popliteal vein to the distal segment of the popliteal artery. Good circulation was maintained through the venous segment and into the popliteal artery, and feeble dorsalis pedis and posterior tibial pulses were palpable during the brief (6-day) postoperative period of observation. In 1907 Lexer¹³ reported a case in which he repaired a traumatic axillary aneurysm by excising it and then suturing a segment of the saphenous vein into the arterial defect. The patient died of an unrelated cause (delirium tremens) on the fifth postoperative day, but necropsy revealed that the vein graft was intact and the brachial artery patent. Lexer subsequently employed the same technique in several other cases. The first successful vein graft to be recorded in the American literature was performed by Bernheim¹⁴ in 1916. He used such a graft to bridge a defect in the popliteal artery following excision of a syphilitic aneurysm.

⁷ Matas, R.: Operation for the radical cure of aneurysm based upon arteriorrhaphy. *Ann. Surg.* 37: 161-196, Feb 1903.

⁸ Bickham, W. S.: Arteriovenous aneurisms. *Ann. Surg.* 39: 767-775, May 1904.

⁹ Murphy, J. B.: Resection of arteries and veins injured in continuity; end-to-end suture; experimental and clinical research. *Med. Record N. Y.* 51: 73-88, Jan 1897.

¹⁰ Djemil-Pascha: *Über die Arteriennaht.* Kongress Moskow. *Centralblatt f. chir.* 24: 1048, Aug 1897, No. 39.

¹¹ Carrel, A., and Guthrie, C. C.: Uniterminal and biterminal venous transplantations. *Surg., Gynec. & Obst.* 2: 266-286, Mar 1906.

¹² Goyanes, J.: Nuevos trabajos de cirugía vascular; sustitución plástica de las arterias por las venas, ó arterio-plastia venosa, aplicada, como nuevo método, al tratamiento de los aneurismas. *Siglo méd.* 53: 561-564, Sep 1906.

¹³ Lexer, E.: Die ideale Operation des arteriellen und des arteriell-venösen Aneurysma. *Arch. f. klin. Chir.* 83: 459-477, 1907.

¹⁴ Bernheim, B. M.: Ideal operation for aneurisms of the extremity; report of a case. *Bull. Johns Hopkins Hosp.* 27: 93-95, Apr 1916.

Between World Wars I and II increased knowledge regarding the peripheral circulation radically altered the surgical approach to arterial lesions. The surgeon of the Second World War was far better equipped to handle casualties with vascular injuries than was the surgeon of the First World War. It is true that results achieved in the treatment of acute arterial injuries were little, if any, better in World War II than in the earlier war. On the other hand, the record of the vascular centers established in the Zone of Interior in the Second World War for the definitive treatment of arterial injuries was extremely impressive. This record can be attributed in part to a better understanding of fundamental physiologic mechanisms and to developments in the basic medical sciences. In addition, advances in anesthesiology, chemotherapy, and adjuvant supportive measures, particularly the use of whole blood transfusions, played an important role. From the standpoint of technique, of course, the good results obtained could be attributed to the careful and general application of Halsted's principles concerning the handling of tissues and to the surgical teachings of Matas, particularly to his emphasis on the importance of the preservation of all collateral vessels.

In general the surgical methods for the management of arterial aneurysms which were being employed at the outbreak of World War II were:

1. the endoaneurysmorrhaphy devised by Matas;
2. measures designed to produce a clot in the aneurysmal sac or to induce the formation of fibrous tissue about it and thus prevent further expansion and possible rupture;
3. obliteration of the sac by closure of the offending vessel;
4. extirpation of the aneurysm-bearing portion of the artery; and
5. extirpation of the lesion combined with some procedure which permitted maintenance or reestablishment of the continuity of the affected artery.

Surgical methods for the management of arteriovenous fistulas were in general:

1. mass ligation of the fistula;
2. quadruple ligation and division of the main vessels with excision of the fistula;
3. transvenous closure of the arterial opening; and
4. repair of the opening in both artery and vein.

While it had long been recognized that the ideal method of management of arterial aneurysms and arteriovenous fistulas involving important arteries was some procedure which would permit the maintenance or restoration of the continuity of the affected artery, the general feeling was that operations of this kind were fraught with too much risk to justify their extensive clinical use. However, technical improvements in vascular surgery and the development of the means of combating postoperative thrombosis had begun to alter this situation, and by the time World War II commenced the total number of clinical cases in which some type of reparative surgery was being performed was on the increase.

In World War II the large numbers of patients with arterial lesions and their concentration in the three vascular centers in the Zone of Interior where they were cared for by experienced vascular surgeons, permitted the selection of numerous cases for reparative surgery. This chapter is concerned with a report of that experience at the vascular centers of DeWitt General Hospital and Mayo General Hospital.

CRITERIA FOR SELECTION OF CASES

The attitude of the surgeon, perhaps more than any other single consideration, determines whether or not reparative procedures shall be applied in the management of arterial aneurysms and arteriovenous fistulas. At the vascular center of Mayo General Hospital it was originally the practice to use this method of treatment only in those cases in which it was reasonably certain that normal arterial structure could be utilized and in which the operation could be performed without undue difficulty. An examination of those cases in which the lesion involved the arteries upon which the main blood supply to a part is dependent and in which repair is most desirable—innominate, common carotid and extracranial portion of the internal carotid; the subclavian, axillary, brachial, iliac, common femoral, and popliteal arteries—revealed that only 4 reparative procedures had been carried out in the first 138 cases handled at this center. This amounted to 2.9 percent. After this assessment of the situation it was decided that repair would be carried out in every instance in which it could possibly be performed without sacrificing collateral arteries and without leaving in situ obviously badly damaged portions of arteries. This altered approach resulted in the use of reparative procedures in 30 of the last 57 cases handled in this vascular center (52.6 percent). At DeWitt General Hospital this altered approach resulted in the use of reparative procedures in 23 of 67 patients operated upon for arterial lesions between June and November of 1945 (34.3 percent).

In a few cases reparative surgery was undertaken when the outcome was questionable because of the degree of local damage and the presence of infection, but this was done in the hope that success would follow and the indications for reparative methods would be, thereby, extended. While it is true that almost all of the failures occurred in this group, it is also true that results in many of the questionable cases were successful.

Problems of Arterial Repair

Although the attitude of the surgeon is of paramount importance in the application of reparative procedures to the surgery of aneurysms and fistulas, the anatomic situation revealed at operation often precludes reparative surgery. In the first place there may be thrombosis of the distal artery. In a number of cases this has made impossible any arterial repair. According to Bigger,¹⁵

¹⁵ Bigger, I. A.: Treatment of traumatic aneurysms and arteriovenous fistulas. Arch. Surg. 49: 170-179, Sep 1944.

calcification of the wall of the artery in the area to be sutured represents the most important contraindication to repair. Extensive arterial obliterative disease has also often made arterial repair impossible, though this factor was not of importance in the aneurysms and arteriovenous fistulas observed during World War II because most of them were of traumatic origin. However, repair under unfavorable circumstances was sometimes attended with success. In one case treated at a vascular center in the Zone of Interior, vein graft was successful in spite of extensive medionecrosis of the popliteal artery (Table 32, Case 32).

In traumatic lesions, extensive damage to the artery is often a determining factor in preventing restoration of continuity, at least by the simpler means such as lateral arteriorrhaphy or end-to-end anastomosis. In contrast to the limited injury to the artery which is the rule when aneurysms or fistulas have resulted from stab wounds, for example, there is generally extensive injury when these lesions have resulted from shell fragments, land mines, or bullets, as was the case in almost all of the patients observed at the vascular centers. There is frequently gross and much more often microscopic injury to the artery, not only in the immediate neighborhood of the aneurysm or fistula, but some distance from it. Whether the damage which is evident only on microscopic examination is a real threat to successful arterial repair is still an unsettled question. The military experience of World War II did not solve this problem.

A fairly common contraindication to end-to-end suture or vein graft is the presence of an important collateral vessel so near the end of the undamaged portion of the artery that to utilize these methods of repair would mean to sacrifice the collateral vessel. Except in the occasional case in which circumstances are such that continuity of the artery can safely be maintained by some simpler procedure such as ligation and transfixion of a fistula, definitive surgery should not be undertaken without good evidence that the collateral circulation is entirely satisfactory. It is almost never the part of wisdom to sacrifice a sizeable collateral vessel in order to achieve preservation of the artery. This principle was never violated in the cases observed in the vascular centers in the Zone of Interior during World War II.

Arteriovenous communications are frequently not simple fistulas but are associated with one or several saccular aneurysms as well. Sometimes these aneurysms arise from the veins or from the fistula itself, but often they originate in the artery and can be corrected only by excision of the involved segment. When this is necessary, unless the ends of the vessel can be mobilized sufficiently to permit approximation, a vein transplant is the only means of restoring an arterial vessel. Such a transplant is an ingenious means of bridging an arterial defect, but the threat of thrombosis is probably greater when this technique is employed than when end-to-end suture or lateral arteriorrhaphy is employed.

It should be noted that associated nerve lesions requiring suture were not considered a contraindication to arterial repair. Nerve lesions were present

in a number of the combat-incurred vascular lesions discussed in this chapter but they presented few difficulties of management. The usual procedure was (1) to dissect free the involved nerve or nerves, (2) to excise the aneurysm or fistula totally or subtotally, (3) to accomplish arterial repair, and (4) to perform the necessary nerve surgery.

The chief local factors which endanger the success of the repair appear to be damage to the wall of the artery (a determining factor in repair in many of these lesions which were of traumatic origin), infection, and a lumen of such small diameter as to make difficult accurate approximation of the parts.

TECHNICAL CONSIDERATIONS IN VASCULAR REPAIR

The general principles of vascular surgery were carefully observed in all reparative operations. Asepsis was strictly maintained. All the vessels were handled gently to avoid local injury, and the intima was always kept moist with physiologic salt solution or mineral oil. Nontraumatizing methods were employed to occlude the blood supply—rubber-shod serrefine artery clamps were used at Mayo, rubber tubing clamped close to the vessel wall by means of fine curved hemostats at DeWitt. The edges of the vessels were carefully brought together with fine suture material in such a way as to approximate intima-to-intima. Care was always taken not to allow the adventitia to fall within the suture line.

Complete control of the arterial supply to an arteriovenous fistula is essential for repair. Occlusion of the principal afferent and efferent arteries often does not suffice. At the vascular centers the use of a sterile stethoscope at the time of operation was found to be invaluable in confirming the completeness of the control of the arterial components. Persistence of a bruit signified that some additional arterial supply was present.

Complete control of the venous component facilitates the repair, but such control may require prolonged and tedious dissection and may result in destruction of collateral vessels. In 7 patients at the vascular center of DeWitt General Hospital, control of the arteries alone was achieved. At the moment of severing the connection between the artery and the vein or the aneurysmal sac, digital pressure was used to control the venous bleeding. Suture of the open vein was then readily accomplished. In 5 patients at this center, after the afferent and efferent arteries had been isolated, a pneumatic tourniquet, which had previously been placed about the extremity at a higher level, was inflated. This procedure was not especially useful since the venous system in the presence of an arteriovenous fistula is capacious and therefore already full of blood. In all of these cases retrograde bleeding necessitated digital pressure in addition to the use of the tourniquet. In several instances the venous pressure appeared to be even higher when the tourniquet was used than when it was not.

Careful inspection of the wall of the damaged portion of the artery was another important phase of the reparative procedure. The incidence of additional points of damage of the arterial wall in the presence of arteriovenous fistulas is high. After irrigation of the lumen of the artery, the entire wall was carefully inspected both from within and from without. Two defects each, for instance, were present in arteries of 6 of the patients in the DeWitt General Hospital series, the first communicating with the main vein and the second with an aneurysmal cavity or another vein. In a seventh patient three venous communications were present. One objection to the transvenous method of closure is that additional defects or weak points in the arterial wall may be overlooked.

At the vascular center of DeWitt General Hospital excision of the damaged arterial wall was the preferred method. After excision of part of the arterial wall the resultant defect was closed by approximation of its edges. Usually, in the presence of an arteriovenous fistula, the artery, especially the proximal portion, has become so dilated that sufficient length is readily available. The preference at this installation was to use any sound portion of the arterial wall, even to one-sixth of the circumference (Case 13) rather than to perform a complete transection of the vessel with end-to-end anastomosis. In 11 patients at this center a portion of the arterial wall was excised. The use of the wall of the sac, or of a segment of vein, to reconstruct the arterial wall was not practiced on the ground that this tissue, which is largely fibrous, cannot withstand the increased pressure to which it is subjected in its new location. The recurrence of the arterial aneurysm in a patient at the DeWitt General Hospital (Case 11) was thought to be an illustration of the futility of using anything but normal arterial wall in the repair.

Transverse closure of the defect in the arterial wall sometimes produces distortion of the wall and turbulence of the blood stream. Auscultation over the vessel at the suture line occasionally reveals a loud, sharp, systolic murmur which may be audible through the skin and soft tissues even after healing has taken place. It was the experience at DeWitt General Hospital where 16 patients were treated by this method of repair, that in the absence of a diastolic component the murmur is without significance. The distortion of the vessel which may be produced by the transverse closure is, in fact, likely to be advantageous: The greater diameter at the point of closure may serve to prevent thrombosis and thus may increase the likelihood of a successful repair.

At DeWitt General Hospital approximation of the edges of the incised vessels was facilitated by manipulating the rubber tubing and clamps which had been placed above and below the fistula to occlude the artery. If this maneuver did not work, additional relaxation was obtained by dissecting the artery up to the point of origin of the nearest branch. However, no important collateral vessel was sacrificed.

At the vascular center of Mayo General Hospital in instances of arteriovenous fistula in which the fistula was not closed by ligation and transfixion or

by lateral arteriorrhaphy, the affected segment of both artery and vein, together with the fistula, was excised. Repair was then accomplished by end-to-end suture or by vein transplantation. The same procedures were employed in a number of instances following excision of aneurysms.

At this center when end-to-end suture or interpolation of a vein graft was carried out, the procedure was facilitated by first placing 4 interrupted mattress sutures according to the suggestion of Frouin.¹⁶ It was felt that 4 sutures could be spaced more accurately at equidistant points than could 3 traction sutures according to the method of Carrel.¹⁷ It was not felt necessary to utilize an instrument for holding the sutures such as that devised by Horsley.¹⁸

At DeWitt the practice was to suture the opening into the vein after severing the connection between the artery and the vein or aneurysmal sac. When the artery had been disconnected the opening into the vein was closed longitudinally with a running stitch. This procedure was employed mainly for the purpose of simplicity in dealing with the venous component of the fistula since it is rarely necessary to repair the vein. In one patient (Table 29, Case 4) the continuity of the left innominate vein was deliberately preserved since the thoracic duct empties into it. No instance of thrombophlebitis or pulmonary embolism was encountered at this center although thrombosis occurred in a few cases. These complications therefore seem to be no more of a hazard after suture of the vein than after its ligation.

In contrast to the practice of suturing the opening into the vein as practiced at DeWitt, it was the policy at the vascular center of Mayo General Hospital to divide and ligate the vein rather than repair it.

Although differences of opinion concerning the best suture material for vascular surgery still exist, it has long been established that only the finest nonabsorbable sutures should be used. Silk, which is generally preferred, was used in all instances at DeWitt General Hospital. Silk suture material was not available at Mayo General and No. 120 cotton suture material was substituted. That this material is satisfactory is shown by the many successful cases in the Mayo series.

Practically every type of suture has been recommended for vascular surgery including continuous sutures, interrupted sutures, continuous mattress sutures, interrupted everting mattress sutures, and continuous cobbler's sutures. At Mayo interrupted everting mattress sutures were used for all reparative operations because they gave satisfactory assurance of accurate, intimal approximation without interposition of adventitia and because such anastomoses could be accomplished without noticeable constriction. Fine straight or curved artery needles were used.

¹⁶ Frouin, A.: Sur la suture des vaisseaux. *Presse méd.* 16: 233-236, 1908.

¹⁷ Carrel, A.: La technique opératoire des anastomoses vasculaires et la transplantation des viscéres. *Lyon méd.* 98: 859-864, 1902.

¹⁸ Horsley, J. Shelton: *Surgery of the Blood Vessels*. St. Louis, C. V. Mosby Co., 1915.

TABLE 29. LIGATION AND TRANSFIXION OF FISTULA—DATA ON 13 PATIENTS WITH ARTERIOVENOUS FISTULAS

Case No.	Age of patient	Location of lesion	Duration of lesion	Preoperative sympathectomy	Anti-coagulant therapy	Diameter of fistula	Post-operative observation	Results
			<i>Months</i>			<i>Mm.</i>	<i>Months</i>	
1	36	Carotid at bifurcation	9.0	□	0	3	1.5	Excellent.
2	31	Common carotid	4.0	0	0	10	1.0	Excellent.
3	22	Common carotid	4.5	0	0	5	1.0	Excellent.
4	26	Popliteal, middle 3d	9.0	+	0	7	4.0	Excellent except for slight edema of ankle.
5	35	Popliteal, middle 3d	9.0	+	0	5	1.0	Excellent.
6	19	Popliteal, distal 3d	6.0	+	+	6	2.0	Excellent except for slight edema of ankle.
7	45	Popliteal, middle 3d	10.0	+	0	5	1.0	Excellent.
8	20	Femoral, middle 3d	9.0	+	+	5	1.0	Excellent.
9	27	Femoral, proximal 3d	11.0	+	0	■	1.0	Excellent.
10	25	Femoral, proximal 3d	6.0	□	+	4	1.0	Excellent.
11	32	Femoral, proximal 3d	7.0	+	0	5	1.0	Excellent.
12	23	Femoral, proximal 3d	Unknown	+	0	3	1.5	Excellent.
13	21	Axillary, distal 3d	4.5	0	¹ +	3	1.0	Recurrence in 2 days; excision 2 weeks later, good results.

¹ Single 50-mg. dose of heparin at time of operation.

At DeWitt General Hospital a running stitch was used which passed through all layers. The suture material was usually doubled back on itself and tied at the point of origin. No. 0000 silk, passed through sterile mineral oil, was used on an atraumatic needle. Bleeding from the suture line was seldom of any consequence and usually stopped spontaneously. When it did not, an additional stitch of No. 00000 silk was added.

Mechanical aids were not used in the reparative operations in any case in these two series. Permanent nonabsorbable intraluminal prosthesis are doomed to failure because of thrombosis, and no need was felt for the employment of removable glass splints or soluble rods in these cases. For various reasons the vitallium tubes introduced by Blakemore, Lord, and Stefko¹⁹ were not used: The sutured vessel has no permanent, rigid, nonabsorbable, partially constricting ring about it, as does a vessel repaired by the vitallium tube method, and in the hands of those experienced in vascular surgery the suture method carries less risk of subsequent hemorrhage and the occurrence of thrombosis is not significantly increased. Moreover, the nonsuture method is attended with certain difficulties. In several cases at the Mayo General Hospital in which its use was contemplated, a vein of suitable size could not be found. In one or two other cases the tubes could not be used because their length would have necessitated occlusion of a collateral vessel which lay near the damaged portion of the artery. In one case in which a vein graft had been completed by the

¹⁹ Blakemore, A. H.; Lord, J. W., and Stefko, P.: Severed primary artery in war wounded; nonsuture method of bridging arterial defects. *Surgery* 12: 488-508, Sep 1942.

nonsuture method, a brisk hemorrhage occurred as the wound was being closed because the tube slipped out of the proximal artery even though it had been tightly anchored in place with several silk ligatures.

Even when arterial repair had been planned and was thought to be practical, the endeavor was made, in every case in these two series, to make certain that collateral circulation was adequate. Furthermore, as much care was used at operation to preserve all collateral vessels as if ligation of the affected artery were to be carried out. In retrospect it would seem to be wise to reexamine the collateral circulation at the time of operation during temporary occlusion of collateral arteries in cases in which by sacrificing one or more of them the repair of the main artery might be accomplished. Reparative procedures might have been undertaken in a number of other cases if this special technique had been used routinely and the efficacy of the collateral circulation established at the time of operation.

VASCULAR REPAIR AT DEWITT GENERAL HOSPITAL

Analysis of Data

Between June and November 1945 restoration of the continuity of the artery was attempted in 23 patients with aneurysms and arteriovenous fistulas at the vascular center of DeWitt General Hospital. (During this period 67 patients with arterial injuries were treated by surgical intervention.) This number (23) includes a patient with arteriovenous fistula of the abdominal aorta which, because of its rarity, is described in detail later in the volume. (See Chapter IX.)

Successful results were achieved in 18 of the 23 cases, including, in addition to the fistula involving the abdominal aorta, 3 lesions of the common carotid artery, 7 of the popliteal artery, 4 of the superficial femoral artery, and 1 each of the subclavian, brachial, and posterior tibial arteries. Longitudinal suture was employed in 2 instances, end-to-end anastomosis in 1, and transverse suture in 15.

Failure occurred in 5 of the 23 cases. In 1 patient treated by transvenous suture, initial success was followed by recurrence of the lesion. In another patient, this one treated by transverse suture, initial success was also followed by recurrence which necessitated subsequent excision of the fistula. The 3 remaining patients, in all of whom the operation failed, were treated by transverse suture, transvenous suture, and end-to-end anastomosis, respectively.

For two reasons anticoagulant therapy was not used in any of the patients operated on at DeWitt General Hospital: It was believed that (1) the reestablishment of an adequate lumen was sufficient to prevent thrombosis, and (2) complications which could conceivably arise from the use of these agents contraindicated their employment.

In all of the cases classified as successful, continuity of the artery was demonstrated either by the presence of normal arterial pulsations distal to

the site of repair or by arteriogram. Patency of the vein was demonstrated by phlebogram in 6 patients in whom the venous wall was repaired by longitudinal suture, and venous obstruction was demonstrated by the same method in 6 other patients. The status of the vein in the remaining patients is not known.

Methods of Repair

Four techniques of repair were used at this center: (1) longitudinal suture, (2) transvenous suture, (3) end-to-end anastomosis, and (4) transverse suture. In view of the limited number of successful cases of arterial repair on record in the literature, case histories of certain patients treated by this method at the vascular center of DeWitt General Hospital are presented herewith. These are representative of the various types of reparative procedures employed at this center.

Longitudinal Suture

Case 1. A 23-year-old infantry sergeant was wounded by shell fragments 21 November 1944. Approximately 2 weeks later a pulsating mass was discovered on the anterior aspect of the right thigh. This increased in size for a period and then remained stationary.

The patient was transferred to the vascular center of DeWitt General Hospital. At the time of admittance physical examination disclosed the presence of a large tumor on the anteromedial aspect of the right thigh. Over it a loud, continuous bruit could be heard. An arteriogram taken 9 February 1945, showed a large arteriovenous aneurysm involving the superficial femoral artery and vein. This aneurysm measured 13 by 8.5 cm. in diameter. A phlebogram taken 2 March 1945, demonstrated displacement of the saphenous vein to the medial side of the thigh.

After sufficient time had been allowed for the development of a collateral circulation, an operation was performed 28 June 1945. Continuous spinal anesthesia was used. An incision was made over Hunter's canal above the aneurysm. After the dilated superficial femoral artery had been encircled with rubber tubing, the incision was carried down the thigh over the aneurysmal sac, and the sartorius muscle reflected medially to expose the superficial femoral artery and vein below the sac. The artery at this level was also encircled by rubber tubing. No attempt was made to control the blood flow through the femoral vein.

The artery was dissected free from the aneurysmal sac and venous bleeding from the opening into the sac controlled by digital pressure. The defect in the arterial wall measured approximately 1.5 cm. in length. It was closed with a continuous stitch of No. 0000 silk on an atraumatic needle. During this phase of the procedure the lumen of the vessel was irrigated with physiologic salt solution. After completion of the suture, the lower and then the upper rubber tubes were released. Good expansile pulsation across the suture line was observed.

The sac was then opened widely and bleeding from the two orifices of the femoral vein controlled by digital pressure until the ends could be dissected free from the sac and ligated individually. No effort was made to excise the sac. A rubber tissue drain was brought out from the lower end of the wound, and the wound was then closed in layers.

The circulation to the foot and leg appeared to be excellent after operation. An arteriogram taken 27 July 1945 demonstrated the patency of the superficial femoral artery although the lumen was considerably diminished at the point at which the defect had been repaired.

Although pulsations of the peripheral arteries were normal, oscillometric readings 4 months after operation showed that there was still some impairment of circulation. Seven months after operation the patient still complained of aching in the leg after walking six blocks.

Case 2. A 23-year-old infantryman was wounded in the right side of the neck 13 February 1945 by a shell fragment. Immediately after injury he noted hoarseness. Debridement was performed, followed by secondary closure of the wound. A few hours later he noted a thrill in the region of the wound. A slight ptosis of the right eyelid was also observed. All symptoms and signs persisted up to the time he was admitted to DeWitt General Hospital.

Physical examination at that time revealed the classical signs of an arteriovenous fistula involving the right side of the neck just above the clavicle. Laryngoscopic examination showed, in addition, paralysis of the right vocal cord. Pressure upon the fistula caused a paroxysm of coughing. The bruit could be made to disappear by applying pressure over the common carotid artery behind the clavicle. This procedure did not produce any symptoms of cerebral ischemia.

An operation was performed 2 August 1945, with the patient under intratracheal nitrous oxide-ether-oxygen anesthesia. A transverse incision was made above the right clavicle. The muscles were divided close to their insertion and the greatly dilated internal jugular vein exposed. The inferior thyroid vein was divided and the common carotid artery, which appeared about normal in size, dissected free. Compression with a piece of rubber tubing did not entirely obliterate the bruit heard over the fistula. Dissection was therefore carried above the fistula, and the common carotid artery isolated and surrounded by a second piece of rubber tubing. Compression of the artery both above and below the fistula reduced the bruit, but did not completely abolish it. Digital palpation revealed the presence of another large artery lying beneath the fascia lateral to the jugular vein. This artery, which proved to be the inferior thyroid, was divided above and below the fistula. Following this procedure no bruit was audible when the contributory vessels were compressed. Accordingly, the jugular vein was ligated above and below the fistula and the carotid artery dissected away from the aneurysm. The defect in the wall of the carotid was closed with a longitudinal running stitch and the segments of the jugular vein, with the aneurysm which lay posterior to it, excised.

The wound was closed in layers without drainage. Good pulsation was present in the distal part of the carotid artery 1 hour after suture. Convalescence was uneventful. When the patient was discharged 4 weeks after operation pulsation of the right temporal artery was normal. This pulsation was not affected by compression of the left carotid artery though it was obliterated when compression was made on the right side of the neck. Six months later the patient reported that his only residual symptoms were hoarseness and some drooping of the right eyelid. There was no evidence of recurrence of the aneurysm and he was able to exercise as much as he desired.

Comment. Longitudinal closure of the defect in the arterial wall was successfully accomplished in these 2 patients. When the opening is small, distortion of the arterial wall by suture is not great. In larger defects, however, distortion of the normal contour resulting from suture may curtail the volume of blood flowing through the restored artery. Reinforcement of the suture line by the use of a part of the sac wall may still further reduce the caliber of the vessel. Waugh²⁰ reported a case in which the diameter of the vessel was reduced one-half by this procedure. The maintenance of a full volume flow of blood past the suture line seems to be of importance in preventing subsequent thrombosis at this site.

²⁰ Waugh, W. G.: Arteriovenous aneurysm of the popliteal vessels; arteriorrhaphy under heparin. *Brit. J. Surg.* 31: 192-193, Oct 1943.

Transvenous Suture

Case 3. A 28-year-old infantry private was wounded in left knee by a rifle bullet 13 March 1945. There was considerable hemorrhage initially and bleeding recurred on several occasions. He was admitted to the vascular center of DeWitt General Hospital 6 April 1945. At this time there was considerable swelling of the left calf and ankle. A pulsating mass was present in the popliteal space over which was observed the characteristic thrill and bruit of an arteriovenous fistula. Pulsations about the left ankle were absent and oscillographic readings showed a marked decrease in the circulation. An arteriogram 12 April revealed an arteriovenous fistula at the level of the head of the fibula. Dye was present in the veins on both sides of the artery, but the significance of this observation was not realized until later. Lumbar sympathectomy performed 13 August was followed by improvement in the collateral time and in the circulation to the left foot.

The vascular operation was performed 13 September 1945. Continuous spinal anesthesia was used. The involved vessels were exposed between the heads of the gastrocnemius muscle in the lower portion of the popliteal space where the popliteal artery lay between the two veins. Without separation of the veins from the artery the entire vascular bundle was encircled by rubber tubing both above and below the fistula. Each vein was opened in turn and its communication with the artery visualized. The opening on each side was approximately 7 mm. long. Each was closed longitudinally, according to the Matas-Bickham technique,²¹ using a running stitch of No. 0000 silk on an atraumatic needle. The sutures were tied outside of the vein. When the upper tube was released a small amount of bleeding from the artery into one of the veins was observed and two additional stitches were taken in the suture line within this vein. At the conclusion of this procedure there was no further bleeding.

The incision on the posterior surface of the vein was closed with a running longitudinal stitch, after which all of the blood vessels were released. Auscultation revealed a very faint continuous bruit in the region of the fistula. Further dissection failed to disclose its source and it was assumed that it resulted from the turbulence of the blood stream as it passed over the suture lines. The wound was closed without drainage.

Following the operation the posterior tibial pulse was excellent and oscillographic readings showed a considerable improvement in the circulation to the left leg and foot. Auscultation, however, revealed the same faint continuous bruit with systolic accentuation heard during the operative procedure.

The patient was then sent on a convalescent furlough. Upon his return he stated that while walking one day he had suddenly felt something snap and upon palpation had noticed a recurrence of the thrill. When he was reexamined a loud continuous bruit was audible.

The second vascular operation was performed 17 November 1945. A longitudinal incision was made posterior to the head of the fibula and was extended upward medially to the biceps tendon. The peroneal nerve was exposed and retracted laterally and the lateral head of the gastrocnemius muscle retracted posteriorly to expose the popliteal vessels as they passed through the ring of the soleus muscle. An aneurysm measuring 2 cm. in diameter was found at this point. The artery above the aneurysm was freed and encircled by a piece of rubber tubing, compression of the artery by this tubing obliterated the bruit.

The head of the soleus muscle was then divided close to its attachment to the head of the fibula and retracted posteriorly together with its nerve and blood supply. The popliteal artery was thus exposed below the aneurysm. At this point there was a moderately dilated vein lying over the artery. It was possible to observe the turbulent flow of mixed arterial and venous blood in it. This vein was divided and ligated in order to expose the popliteal artery below the fistula. The artery was again encircled by a piece of rubber

²¹ See footnotes 6, p. 264, 7, and 8, p. 265.

tubing. The proximal and distal arteries were divided and ligated; the component veins were treated similarly and the aneurysm excised. Examination of the specimen revealed two openings from the artery, a small one, communicating with a small vein, which had apparently been overlooked at the original operation, and a larger one which was the result of a rupture of the artery into the vein at the point where it had been sutured at the original operation.

Recovery from the second operation was without complications, but thereafter the circulation to the left foot was definitely decreased. Oscillations at the ankle were less than one-fourth of those on the normal side. In spite of this fact, the circulation was fairly well maintained and the patient was able to walk as many as three blocks before signs of intermittent claudication developed.

Case 4. A 24-year-old sergeant was struck by a shell fragment just above the left clavicle 29 July 1944. It was noted after the initial debridement that the left radial pulse was absent although it subsequently returned. The patient stated that from the time of the injury he believed the temperature of the left upper extremity was lower than that of the right upper extremity. Except for difficulty in articulation for the first few days after injury, he had no complaints. However, a loud continuous bruit was audible over the left sternoclavicular joint.

When he was admitted to the vascular center at DeWitt General Hospital in October 1944, his venous pressure was 16.4 cm. of water on the left side and 13.4 cm. on the right in the antecubital vein. The circulation time was 20 seconds on the left and 9 on the right. At examination, attempts to compress the aneurysm by pressure in the supraclavicular region were unsuccessful. In spite of the fact that the aneurysm was close to the heart, no evidence of cardiac enlargement was noted during a long period of observation.

An operation was performed 10 September 1945 with the patient under endotracheal nitrous oxide-ether-oxygen anesthesia. A transverse supraclavicular incision was made on the left side and extended down over the manubrium to the second rib, thence laterally to the costochondral junction (Fig. 36). The muscles attached to the clavicle and the sternum were divided close to their insertions. The internal jugular vein was thus exposed and the turbulent mixing of arterial and venous blood characteristic of arteriovenous fistula could be observed. Pressure on the junction of the internal jugular and subclavian veins stopped the bruit in the fistula.

The common carotid artery on the left side was then exposed; its pulsation was found to be feeble and its wall thick. Occlusion of this artery, however, did not eliminate the thrill in the aneurysm. Further dissection revealed a greatly dilated innominate vein which it was impossible to expose adequately without opening the thorax. Accordingly, the medial 2.5 inches of the left clavicle were resected subperiosteally, and the sternoclavicular articulation left intact. The tissues were then freed beneath the sternum in the midline and the manubrium split to the upper border of the second rib and then cut transversely at this level. The left half of the manubrium was now readily retracted laterally to expose the thymus lying on the large dilated innominate vein. Some branches of this vein were ligated and divided. The innominate vein and left carotid artery were retracted medially to expose the left subclavian artery as it arose from the arch of the aorta. The subclavian artery was considerably larger than the carotid, its walls were thin and the pressure within it seemed to be low. It was encircled by a fine catheter fitted to a Bethune tourniquet. Compression of the subclavian artery at the arch of the aorta obliterated the thrill in the aneurysm. The bruit also ceased abruptly as soon as the subclavian artery was compressed but after a short interval it was again faintly audible. The recurrence of the bruit was thought to be indicative of collateral circulation.

The internal jugular vein was then divided above its junction with the subclavian. Dissection on the medial side of this vein revealed a large lymphatic duct which entered the jugular vein at its junction with the subclavian. The phrenic nerve was retracted

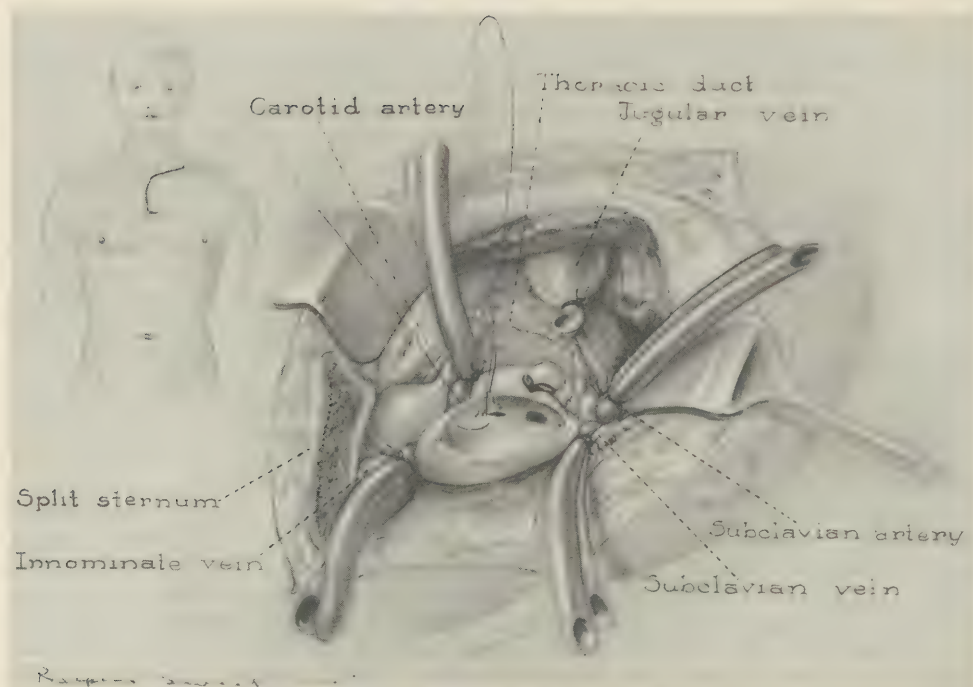


Figure 36. (Case 4.) Transvenous repair of arteriovenous fistula involving left subclavian artery and innominate vein. Insert shows surgical approach to lesion.

medially and the scalenus anticus muscle divided in order to expose the second portion of the subclavian artery. The internal mammary artery was carefully preserved, but the costocervical and the thyrocervical trunks were ligated. The subclavian artery distal to the fistula was greatly reduced in caliber; it was encircled in this location by a piece of rubber tubing. The first portion of the subclavian artery just proximal to the origin of the vertebral artery was then exposed and encircled by a second piece of rubber tubing. When the subclavian artery had been compressed just proximal to the vertebral artery and distal to the fistula, and the vertebral artery had also been compressed, the bruit was abolished and the innominate vein no longer filled with arterial blood.

The subclavian and innominate veins were then occluded by additional pieces of rubber tubing after which the innominate vein was opened on its anterior aspect close to the junction of the jugular with the subclavian vein and flushed out with physiologic saline solution. It was now possible to see an aperture which measured approximately 1 cm. in length lying over the subclavian artery (Fig. 36). The opening from the artery into the vein was sutured from within the vein by the Matas-Bickham technique, using No. 0000 silk. The suture was started from outside the vessel and was passed into the lumen; then, after the opening had been closed with a running stitch, it was doubled back on itself and its ends brought outside of the vein to be tied at the starting point. After this suture had been completed, the distal artery, the vertebral artery, and the proximal artery were released in that order. Some slight bleeding into the vein was controlled by an additional stitch. The incision on the anteromedial surface of the innominate vein was closed with a running longitudinal stitch. The divided halves of the manubrium were approximated with two steel wire sutures and the muscles and superficial tissues closed in layers.

A wound infection necessitated incision and drainage 2 weeks after the original operation, but recovery thereafter was satisfactory. Although there were no signs of circulatory insufficiency of the left upper extremity, the radial pulse continued to be markedly diminished and oscillometric readings showed reduced circulation on this side. Six weeks after operation a phlebogram demonstrated the patency of the left innominate vein. Five months after operation the patient reported that he had noticed no recurrence of the fistula. He stated, however, that he was short of breath and that he experienced precordial pain on exercise. Since there was no cardiac enlargement even before operation it seemed unlikely that the fistula could have caused serious cardiac disturbance.

Comment. Transvenous suture, although it has been considered a logical procedure, has two decided drawbacks: (1) Since the artery need not be fully mobilized, a second, or even a third, communication may be overlooked. This complication, which has been reported by Reid and McGuire,²² accounted for the persistence of the arteriovenous fistula in Case 3 of this series. (2) The arterial wall may be weakened or defective either close to the fistula or at some other point. Without careful scrutiny, both from within and from without, this damaged area may be overlooked. Subsequent rupture with the formation of an aneurysm may result.

End-to-End Anastomosis

Case 5. A 25-year-old infantryman, shortly after being wounded in the left thigh 15 January 1945, showed signs of an arteriovenous fistula. When admitted to the vascular center at DeWitt General Hospital 15 July 1945, examination revealed the characteristic signs of an arteriovenous fistula. An arteriogram taken on 20 July showed an aneurysmal sac lying to the medial side of the femoral artery with a communication into the lower femoral and popliteal veins. Sympathectomy was performed 30 July. After this operation, the collateral circulation improved and appeared to be adequate.

The vascular operation was performed 23 August 1945. A longitudinal incision was made over the lower part of the adductor canal and the femoral artery exposed above and below the fistula. The aneurysm was found on the lateral side of the artery. After digital compression of the veins the artery was dissected free from the aneurysm and from the veins. The opening into the vein was closed with a longitudinal running stitch. Two large defects were present in the arterial wall. Because so little sound arterial wall remained the damaged portion was excised and an end-to-end anastomosis performed. After release of the rubber tubing expansile pulsation was transmitted across the suture line. The wound was closed without drainage.

The peripheral pulses were good after operation and at the left ankle an oscillometric reading of 3 units was noted in comparison to a reading of 5 units on the uninjured side. The excellent peripheral pulses and the practically normal circulation encouraged the belief that a successful repair had been accomplished, but an arteriogram taken 6 weeks after operation showed that the segment had been completely obliterated and that the circulation was being carried on entirely by means of collateral vessels.

Case 6. A 28-year-old infantryman was wounded in the left thigh by a rifle bullet 28 February 1945. The wound of entrance was 2 inches below Poupart's ligament. Debridement was carried out while the patient was in the forward area. Later an arteriovenous fistula was discovered in the traumatized area of the thigh. The patient was admitted to the vascular center of DeWitt General Hospital 1 July 1945. An arteriogram taken

²² Reid, M. R., and McGuire, J.: Arteriovenous aneurysms. *Ann. Surg.* 108: 643-693, Oct 1938.

7 September 1945 showed a communication between the femoral vessels just distal to the profunda.

An operation was performed 1 October 1945. A semilunar incision, with its center at the wound of entrance, was made over the upper portion of the thigh. The common femoral artery was exposed below Poupart's ligament. It was greatly dilated and its walls were thin. The artery was encircled by a piece of rubber tubing, compression of which obliterated the thrill in the arteriovenous fistula although a slight bruit remained audible. The artery was also exposed below the profunda femoris and a temporary ligature placed about it, but further auscultation revealed that the aneurysm involved the superficial femoral artery below this second temporary ligature. Dissection was accordingly carried farther down the thigh by retracting the sartorius muscle medially and exposing the femoral artery in Hunter's canal. When the artery was occluded both proximally and distally the bruit was completely abolished. The artery was separated from the vein by sharp dissection. Rather brisk venous bleeding was controlled by digital pressure until the femoral vein could be sutured.

Examination now showed that the wall of the femoral artery had been destroyed over a very wide range and that it showed perforations, one on the lateral and one on the medial side. The artery was therefore divided and the damaged portion excised. In order to obtain sufficient relaxation to permit suture, the artery had to be dissected free below for a distance of 2 inches and upward to the point at which the profunda femoris left it. An end-to-end anastomosis was then performed; a continuous running stitch of No. 0000 silk was used. After release of the rubber tubing there was some bleeding which was controlled with additional stitches. At the conclusion of the operation good pulsation was transmitted across the suture line. The wound was closed without drainage.

The peripheral pulses remained excellent and convalescence was uneventful. Oscillographic readings showed no diminution of the circulation on the injured side. An arteriogram and a phlebogram taken 2 months after operation demonstrated patency of the vessels. The patient reported 5 months after operation that he had been working steadily, but that he had pain in the lower part of the leg when standing for a long time or when walking for some distance. There was no swelling in the limb and the circulation was good.

Comment. End-to-end anastomosis was successful in the second of these 2 cases. Obliteration occurred in the first case. The patient recovered, however, since the collateral circulation was abundant and little vascular insufficiency resulted.

Transverse Suture

Case 7. A 24-year-old infantryman was wounded in the neck, arms, and legs by multiple mortar fragments 1 April 1945. Subcutaneous emphysema of the neck developed, but subsided spontaneously. Subsequently characteristic signs of arteriovenous fistula were observed on the left side of the neck at the level of the thyroid cartilage. These signs persisted up to the time he was admitted to the vascular center at DeWitt General Hospital 27 May 1945. Laryngoscopic examination showed, in addition, paralysis of the left vocal cord. Three months after the injury compression of the common carotid artery below the fistula produced no evidence of cerebral ischemia.

An operation (Fig. 37) was performed 23 July 1945. Local anesthesia was used. An oblique incision (Fig. 37A) was made parallel to the skin creases at the level of the thyroid cartilage. Dissection was carried down medially to the sternomastoid muscle, and the common carotid artery was isolated below the fistula. A rubber tube was placed about the artery at this point. The common carotid artery was again isolated and similarly treated above the fistula. The jugular vein was greatly dilated. It was dissected free and a heavy black silk thread placed about it both above and below the fistula. The vagus nerve was then freed to the point at which it was incorporated in the scar between the carotid artery

and the jugular vein. Procaine hydrochloride (1 percent) was injected into the vagus nerve above the line of scar tissue. With the common carotid artery compressed both above and below the fistula, the vagus nerve was dissected free and the communication between the artery and vein opened. The communication measured 1 cm. in diameter.

On inspection of the defect in the arterial wall, which was on the posterolateral side, it was noted that the media was defective in the region of the aperture. The defective portion of the wall was excised. After relaxation of tension had been accomplished, the defect in the arterial wall was closed in a transverse direction (Fig. 37E) by a running stitch doubled back on itself. When the rubber tubing was released, pulsation took place across the suture line. There was no evidence of narrowing of the vessel. The jugular vein was divided between ligatures. The two ends of the vagus nerve were united after excision of the damaged segment. When, at the conclusion of the operation the carotid artery was again examined, good pulsatile flow could be demonstrated above the suture line. The wound was closed in layers without drainage.

Recovery occurred without complications and the patient was discharged from the hospital a month after operation. It was possible, in the postoperative period, to demonstrate the patency of the left common carotid artery by noting that the temporal pulse on the left side was unaffected by compression of the right common carotid artery but could be obliterated by compression of the artery on the left side. Six months after operation no swelling had recurred in the neck, but normal voice had not yet returned. The patient reported he was still unable to work and that he could not exercise as much as he would like because he was "short-winded."

Case 8. A 21-year-old infantryman sustained many wounds of the chest, abdomen, and right leg from mortar shell fragments 21 December 1944. During his hospitalization it was discovered that he had an arteriovenous fistula in the right popliteal space. On his admission to DeWitt General Hospital 28 March 1945, the diagnosis was confirmed. A preoperative arteriogram 22 May showed considerable reflux of dye into the dilated popliteal vein. The communication between the artery and the vein seemed to be at the superior level of the patella. Lumbar sympathectomy was performed 9 July 1945. After this operation the collateral circulation appeared excellent.

The vascular operation was performed 9 August 1945. Continuous caudal anesthesia was used. A Z-shaped incision was made with the transverse bar across the popliteal crease. The incision was deepened along the tendon of the semimembranous muscle. Many small veins were encountered which entered the greatly dilated popliteal vein. Rubber tubing was placed about the entire vascular bundle including both the artery and the vein. Dissection was then carried out below the fistula and the popliteal artery isolated and encircled by a section of rubber tubing. The popliteal vein was surrounded by heavy silk cord. Further dissection above the aneurysm resulted in separation of the artery from the vein so that each could be controlled independently. When the component vessels had been occluded the artery was dissected from the vein and the communication severed. The defect measured 1 cm. in length. The opening in the wall of the vein was closed with a longitudinal running stitch. Since the arterial wall was found to have been damaged for about one-half its circumference, a wedge-shaped portion of the lateral wall was excised and the defect closed in a transverse direction with a continuous suture of No. 0000 silk placed through all coats of the vessel. Some bleeding followed release of the occlusive rubber tubing, but was controlled with a suture. There was only slight reduction in the diameter of the artery at the point of suture and vigorous pulsation was noted below the suture line after release of the rubber tubes. At the conclusion of the operation the posterior tibial pulse was full and bounding. The wound was closed without drainage.

Normal pulses were present during the postoperative period at the right ankle and oscillometric readings showed that the circulation on the right side was almost equal to that of the left. An arteriogram 24 August showed practically no distortion at the suture line.

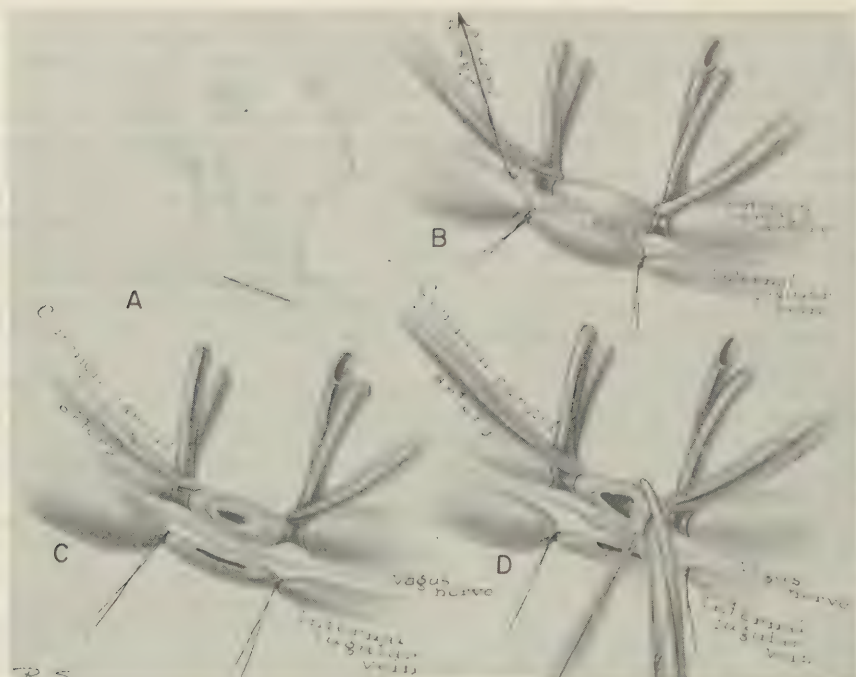
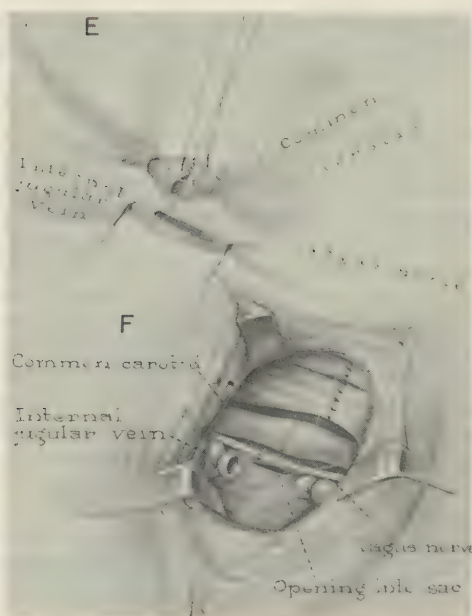


Figure 37. (Case 7.) Carotid-jugular arteriovenous fistula. A. Location of incision. B. Control of circulation through component vessels. C. Division of fistula. D. Excision of damaged portion of arterial wall.



E. Transverse repair of defect in carotid artery.

F. Completion of repair.

Reexamination 4 months after operation disclosed a normal peripheral circulation and 6 months after operation the patient reported that he was able to walk several miles without difficulty.

Case 9. A 22-year-old corporal was struck by a shell fragment 18 July 1944 just above the right clavicle. In addition, he sustained severe wounds of both legs and the left forearm. Amputation of the left forearm was necessary. He was admitted to DeWitt General Hospital 5 March 1945 with classical signs of an arteriovenous fistula at the base of the neck on the right side. It was difficult to obliterate the bruit by pressure above the clavicle. In spite of the length of time between injury and operation there were no signs of cardiac damage.

An operation was performed 20 August 1945 with the patient under endotracheal nitrous oxide-ether-oxygen anesthesia. A supraclavicular incision was made. The muscles attached to the sternum and clavicle were divided at their insertion in order to expose the internal jugular vein. Both the right and left inferior thyroid veins were divided and ligated, and the deep cervical fascia incised. The internal jugular vein was retracted laterally and dissection carried down behind the clavicle to expose the innominate artery. This artery was encircled by a piece of rubber tubing fitted to a Bethune tourniquet. Occlusion of the artery caused marked decrease in the bruit over the fistula. Compression of the common carotid artery did not affect the bruit. The rubber tubing was then transferred to the subclavian artery just proximal to the origin of the vertebral artery. The scalenus anticus muscle was divided, after retraction of the phrenic nerve medially, to expose the second portion of the subclavian artery. The communication appeared to involve the internal jugular vein and the subclavian artery just proximal to the origin of the thyroid axis. The jugular vein was divided and its upper portion ligated. After compression of the subclavian artery proximal and distal to the fistula the vein was dissected free from the artery to expose a small opening approximately 0.5 cm. in diameter. This opening was closed transversely with interrupted stitches of No. 0000 silk. Good pulsation was present in the artery distal to the suture line after release of the occluding rubber tubing. The jugular vein was ligated close to its junction with the right subclavian, and the wound was closed in layers without drainage.

Convalescence was uneventful and at the time of the patient's discharge from the hospital the right radial pulse was normal.

Case 10. A 27-year-old soldier was wounded by shell fragments in the right thigh, trunk, and face 20 January 1945. During his convalescence from these wounds an arteriovenous fistula of the right femoral vessels was noted. He was admitted to the vascular center at DeWitt General Hospital 18 May 1945. An arteriogram (Fig. 38A) taken 20 May 1945 revealed an arteriovenous fistula in the upper portion of the superficial femoral vessels on the right side and, in addition, a small aneurysm on the lateral aspect of the artery. A lumbar sympathectomy was performed 8 August because of impaired circulation. Following this operation there was considerable improvement in the collateral circulation.

The vascular operation was performed 13 September 1945. The superficial femoral artery was exposed in the upper third of the thigh. Rubber tubes were placed about the artery both above and below the fistula. A pneumatic tourniquet was then inflated and the artery dissected away from the vein and from the aneurysm. The aneurysm was found on the posterolateral side of the artery while the opening between the artery and the vein was on the posteromedial side. The opening into the vein was closed with a longitudinal running stitch. The pneumatic tourniquet was then deflated.

The defect in the arterial wall was approximately 1.5 cm. long. The damaged portion of the wall, including the segment between the openings into the vein and the aneurysm, was excised. Approximately three-fourths of the circumference was lacking and in order to approximate the two ends it was necessary to free the artery both above and below the fistula for approximately 1.5 inches. No large branches were found. Because of the location of the arterial defect, the suture line was oblique rather than transverse or longitudinal.

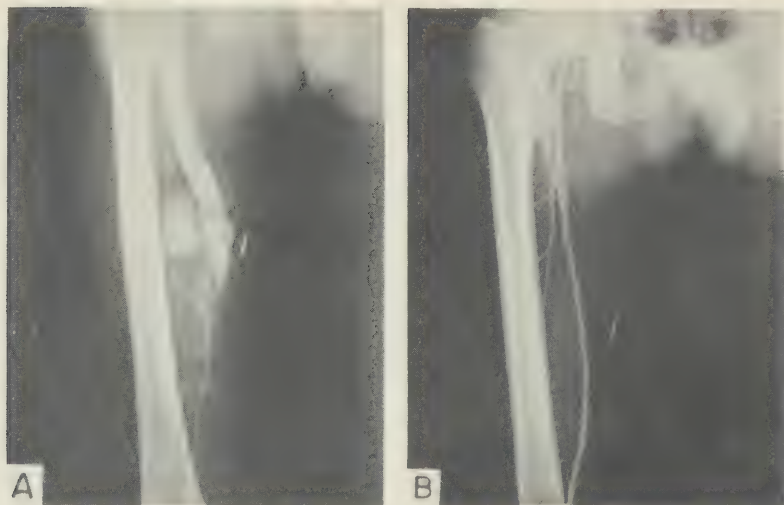


Figure 38. (Case 10.) A. Preoperative arteriogram showing arteriovenous fistula involving upper portions of superficial femoral vessels, with small aneurysm on lateral aspect of artery. B: Postoperative arteriogram following diagonal suture. Note normal continuity of superficial femoral artery.

There was a small amount of bleeding from the suture line after release of the rubber tubing, and an additional stitch was added. Slight distortion of the arterial wall on the side opposite the repair was noted. No attempt was made to remove the aneurysm. The wound was closed without drainage.

Convalescence was uneventful. Oscillometric readings before operation had shown a maximum of 2 units on the right side and 7 on the left, but after repair of the femoral artery the readings were 3 units on the right side and 3.5 on the left. An arteriogram taken 3 months after repair showed normal continuity of the superficial femoral artery (Fig. 38B). A phlebogram demonstrated patency of the femoral vein. Four months after operation, however, the patient reported that he was not able to exercise as much as he desired because his leg became swollen below the knee if he walked too much. There was no recurrence of the arteriovenous fistula nor was there any evidence of swelling in the region of the aneurysm.

Case 11. A 26-year-old infantryman was wounded in the left thigh by shell fragments 30 March 1945. He complained of numbness and tingling in his left foot. A pulsating mass appeared 8 cm. below the inguinal ligament, directly beneath the scar of the wound. He was evacuated to the Zone of Interior and admitted to the vascular center of DeWitt General Hospital. Examination at this center revealed a systolic thrill and a high-pitched bruit, but there was no diastolic component to the murmur. An arteriogram 10 August revealed an aneurysm about 4 cm. in diameter arising from the upper portion of the superficial femoral artery. Lumber sympathectomy was performed 4 October 1945.

The vascular operation was performed 18 October 1945. The superficial femoral artery was exposed above the aneurysm medial to the sartorius muscle. The artery was encircled by rubber tubing. Compression on this tubing caused the aneurysmal sac to collapse. The artery below the aneurysm was then exposed and a tube placed about it to control the retrograde circulation. With both the proximal and distal arteries occluded, the sac was exposed and incised. After removal of the clots and fresh blood the opening of the afferent and efferent portions of the artery were observed to be approximately 1 cm. apart.

The artery was freed from the sac by sharp dissection. There was considerable scar tissue present, as well as some edema. With the aid of traction applied by means of the rubber tubes, the orifices of the artery could be approximated. After cutting away excess portions of the sac, the opening was closed in a transverse fashion with a continuous running stitch. In addition numerous interrupted stitches of silk were used to approximate the scar tissue in the wall of the sac so as to take tension from the suture line. Upon release of the constricting tubing, pulsatile blood flow took place across the suture line. The artery in this location appeared to be quite small and contracted and there was considerable distortion of the superficial femoral artery at the site of suture. The wound was closed without drainage.

The postoperative course was uneventful. Readings taken by oscillometer showed the circulation at the left ankle to be about two-thirds of that of the normal contralateral ankle. An arteriogram 6 weeks after operation revealed considerable distortion of the femoral artery. Three months after operation the patient reported recurrence of the bruit. It was assumed, in view of the considerable degeneration and fibrosis of the arterial wall in the region of the aneurysm, that the scar tissue had given way and that the vascular lesion had recurred. Further treatment was believed to be contraindicated owing to the degeneration of the arterial wall.

Case 12. A 29-year-old officer was wounded in the left thigh by mortar fragments 11 November 1944. He sustained a compound fracture of the left femur. Six weeks later an arteriovenous fistula was discovered close to the site of the fracture. He was admitted to the vascular center at DeWitt General Hospital 8 May 1945. An arteriogram taken 25 May disclosed a simple arteriovenous fistula just below the fracture line. It also revealed considerable distortion of the superficial femoral vein. This was attributed to scar tissue about the fracture. Lumbar sympathectomy performed 13 September was followed by satisfactory improvement in the collateral circulation.

The vascular operation was performed 18 October 1945. Continuous spinal was the anesthetic of choice. An incision was made over the femoral vessel and the sartorius muscle was retracted medially. The superficial femoral artery was exposed above the fistula and rubber tubing was placed about it. Compression of the artery at this point obliterated the bruit of the fistula. The artery was exposed below the fistula and controlled by rubber tubing in this location also. All the small branches of the artery were carefully preserved. The vessels at the site of the fistula were bound down in scar tissue. The communication was exposed by sharp dissection and the artery cut away from the vein during digital compression of the superficial femoral vein above and below the fistula.

The vein was irrigated with physiologic salt solution and closed longitudinally. The defect in the artery measured 1 cm. in length. Its edges were composed of dense scar tissue. The damaged portion of the artery was excised in an elliptical fashion and the opening closed in a transverse direction with a continuous running stitch. There was no bleeding from the suture line after release of the rubber tubing. The suture line occupied approximately three-fourths of the circumference of the vessel and caused considerable distortion. However, good expansile pulsation was transmitted across the suture line. The wound was closed without drainage.

After healing had taken place oscillometric readings showed that there was greater pulsation on the affected side than on the normal side. An arteriogram made after recovery showed some distortion of the superficial femoral artery, but also showed that the lumen had been preserved. Three months after operation the patient reported that there had been no recurrence. His activities were still limited because of the stiffness of his knee resulting from the prolonged period of traction, and he stated that the leg tired more readily than normally.

Case 13. A 23-year-old soldier was struck by fragments from a defective mortar shell 24 September 1945 and incurred multiple wounds of the neck, left shoulder, and arm. One fragment penetrated the left arm just above the elbow and lodged beneath the skin on the medial side. Immediately after injury a wrist drop and some weakness of the left hand developed. He was transferred to a regional hospital after debridement of the wounds. At this installation a pulsatile swelling was noted in the region of the brachial artery above the elbow. As this mass increased in size, progressive paralysis of the median nerve developed. The patient was evacuated to the Zone of Interior and admitted to the vascular center at DeWitt General Hospital 17 October 1945. At that time, pulsations in the vessels at the left wrist could not be detected by means of an oscillogram. Because of the increasing size of the pulsating hematoma and the resulting compression of the median nerve, operation was performed 3 days later.

A longitudinal incision was made on the medial aspect of the arm above the elbow and was curved slightly outward at the lower angle of the wound. When the deep fascia was opened some discoloration of the fat was noted. A pneumatic tourniquet previously applied about the arm was inflated and the hematoma incised. It contained some fresh blood and old clots. The median nerve was exposed and dissected free from the aneurysm. It was found to have become stretched and flattened out as it passed over this tumor. Rubber tubes were passed about the brachial artery above and below the laceration in the wall and the artery separated from the aneurysm. The tourniquet was then released and no further bleeding occurred. The damaged portion of the arterial wall was then excised leaving not more than one-sixth of the circumference intact. The two sections of the artery were approximated and the defect in the wall closed in a transverse direction; a continuous stitch of No. 000000 silk was used. All layers of the arterial wall were included. Though there seemed to be considerable spasm of the proximal portion of the artery, at the conclusion of the operation a good pulsatile flow could be demonstrated distal to the suture line. The cavity of the aneurysm was drained through the wound of entrance on the lateral side of the arm and the incision closed.

Immediately after operation the color of the hand was good and a faint radial pulse was palpable. By the next day the radial pulse had returned to its full volume, and oscillogram readings 2 weeks after operation showed that the pulsations at the wrist were greater on the affected side than on the normal side. An attempt to make an arteriogram was not successful, but since it was possible to obliterate the left radial pulse by pressure applied to the brachial artery just above the elbow, it was concluded that the arterial repair had probably been successful.

Comment. Transverse repair of the artery was successful in 15 of the 17 cases in which it was attempted. Restoration of the continuity of the vessel was demonstrable by arteriogram in 10 of these cases and in the other 5 by the persistence of normal pulses distal to the site of repair. Of the 2 unsuccessful attempts, thrombosis occurred at the suture line in 1 patient, but this was due in part to faulty technique, i. e., failure to obtain adequate control of the artery above the fistula. In the second patient (Case 11) scar tissue of the aneurysmal wall was used to reinforce the suture line. This patient reported the recurrence of the aneurysm and it may be that the scar tissue gave way, permitting a new aneurysm to form.

SUMMARY

The value of arterial repair in the treatment of aneurysms and arteriovenous fistulas has been questioned since the incidence of gangrene after ligation of major arteries of the extremities is negligible. While it is true that gangrene is rare after ligation, the end results are often not favorable. Remarkably little consideration has been given to the results of permanent reduction of the blood supply to the tissues, especially the muscles, distal to the lesion. After ligation the development of collateral circulation will usually suffice to care for the metabolic requirements of the tissues at rest, but it is only rarely that symptoms of impaired circulation are not noted.

In this connection certain studies made at the vascular center of DeWitt General Hospital are of interest. A questionnaire was sent to former patients in whom the popliteal or the femoral artery had been ligated as treatment for arteriovenous fistula. Nine of the 12 individuals who replied complained of restriction in their activities. A similar questionnaire was sent to those in whom the popliteal or the femoral artery had been repaired. Nine of the 11 who replied had no complaints, and the 2 patients with complaints both stated they could walk from 6 to 8 blocks before any symptoms appeared.

The oscillometer provided another means of assessing results of operative procedures. At DeWitt General Hospital a comparison of the oscillometric readings was made between those patients with arteriovenous fistulas treated by ligation and those treated by arterial repair. In 10 patients treated by *ligation* the average oscillometric readings were:

Before operation:	
Affected side.....	2. 72
Normal side.....	5. 0
After operation:	
Affected side.....	0. 75
Normal side.....	4. 0

In the 12 patients treated by *reparative procedures* the average oscillometric values were:

Before operation:	
Affected side.....	2. 77
Normal side.....	4. 44
After operation:	
Affected side.....	3. 85
Normal side.....	3. 79

On the basis of this evaluation, all the advantages seem to lie with repair instead of ligation of the affected artery.

Even conceding that preservation of the continuity of the artery is to be preferred, the question may still be posed as to the possible risk to the patient.

In the past it has been held that this technique was contraindicated because even though the arterial repair was successful, there remained the possibility of recurrence of the fistula or the development of a false aneurysm close to the site of repair. In only 2 patients in this series did the fistula recur. One followed transvenous suture of the popliteal artery and the other recurrence of an arterial aneurysm was reported subsequently by the patient.

The dangers of hemorrhage or infection do not appear to be increased by arterial repair. In only one patient was serious infection encountered.

Thrombosis at the suture line occurred in 3 patients, but the collateral circulation proved sufficient to prevent gangrene. There was nothing to suggest propagation of the thrombus in these patients.

The defect in the wall of the vein was sutured in 18 patients. Phlebograms taken of 12 patients after they had recovered demonstrated the patency of the vein in 6 patients, but in 6 others it was occluded. Neither thrombophlebitis nor pulmonary embolism was encountered in any instance.

It was the opinion at this center that transverse suture of the defect in the arterial wall after excision of the damaged portion was the most satisfactory method of arterial repair.

VASCULAR REPAIR AT MAYO GENERAL HOSPITAL

Analysis of Data

In the course of World War II more than 300 aneurysms and arteriovenous fistulas were observed at the vascular center of Mayo General Hospital. The majority of patients with these lesions were treated by various surgical procedures involving extirpation of the lesion. In 34 patients, including 21 with arteriovenous fistulas and 13 with arterial aneurysms, some type of reparative surgery was employed.

Four techniques of repair were used: (1) ligation or transfixion of the fistula, (2) lateral arteriorrhaphy, (3) end-to-end suture, and (4) vein transplantation. Anticoagulants were usually employed when lateral suture, end-to-end anastomosis, or vein graft were carried out. Except in those instances in which an adequate prothrombin level had been obtained before operation by the administration of dicumarol, it was the policy to give 50 mg. of heparin intravenously as soon as the decision to attempt arterial repair was reached. Heparin was continued at 4-hour intervals until a suitable response had been obtained from dicumarol, administration of which had been started as soon after operation as the prothrombin level could be determined. In most patients dicumarol was continued for 21 days. A small amount of fibrin foam was often placed in the wound. This seemed to give some protection against bleeding from the operative site without adding any risk of intravascular clotting.

*Methods of Repair***Ligation and Transfixion of Fistula**

Thirteen patients with arteriovenous fistulas (Table 29) were treated by ligation and transfixion. The age range in this group was from 19 to 45 years, 11 of the 13 patients were under 36 years of age. The duration of the lesion at the time operation was performed ranged from 4 to 11 months and was 6 months or more in 10 patients. The fistula involved the carotid artery and the jugular vein in 3 instances, the popliteal in 4, the femoral in 5, and the axillary in 1. The saccular aneurysms present in 6 patients arose from the vein in 3 instances, from the fistula in 2, and from the artery in 1. In the last-mentioned patient the aneurysmal sac had a small neck which could be ligated and transfixed. Associated injuries included a fracture of the femur in 1 instance (Case 10) and peripheral nerve injuries in 2 instances (Cases 4 and 6). Neurorrhaphy was performed at the same time as the vascular operation in 1 of these patients and at a later date in the other.

Eight patients were treated by sympathectomy before operation to improve unsatisfactory collateral circulation, and 4 received anticoagulants. In 1 patient (Case 6) heparin was given at the time of operation and continued until a satisfactory prothrombin level had been obtained from dicumarol. In 2 patients (Cases 8 and 10) dicumarol was given preoperatively for several days. In all 3 patients dicumarol was continued for from 2 to 3 weeks. In the fourth patient (Case 13) a single 50-mg. dose of heparin was given at the time of operation.

In 12 of the 13 patients in this group the fistula was ligated and transfixed at the point of its emergence from the artery, then was buttressed by a segment of the divided vein (Fig. 39). In the remaining patient (Case 13) the fistula was simply ligated in continuity without disturbing the artery or vein. Case 13 represents the only failure by the ligation and transfixion technique. Recurrence of the bruit and thrill was observed within 48 hours of operation and a second operation (excision of the fistula and quadruple ligation of the vessels) had to be performed 2 weeks later. The second operation was successful.

Results were good in the other 12 patients. No thrill or bruit could be demonstrated over periods of observation ranging from 1 to 4 months. The affected artery was not demonstrably narrowed or distorted in any instance, nor was it dilated. The two limbs were of equal warmth and color except in those patients upon whom sympathectomy had been performed; in those the affected foot was warmer than the normal foot. All the pulses distal to the site of anastomosis were full and were considered by a number of observers to be about equal to those in the contralateral extremity. In the patients upon whom sympathectomy was not performed oscillometric readings were approximately the same on both sides. In the patients upon whom sympathectomy was performed they were slightly higher on the affected side. The only abnormal physical findings after operation were limited to edema which was present in 2 patients; in both it was slight and became progressively less as time passed.

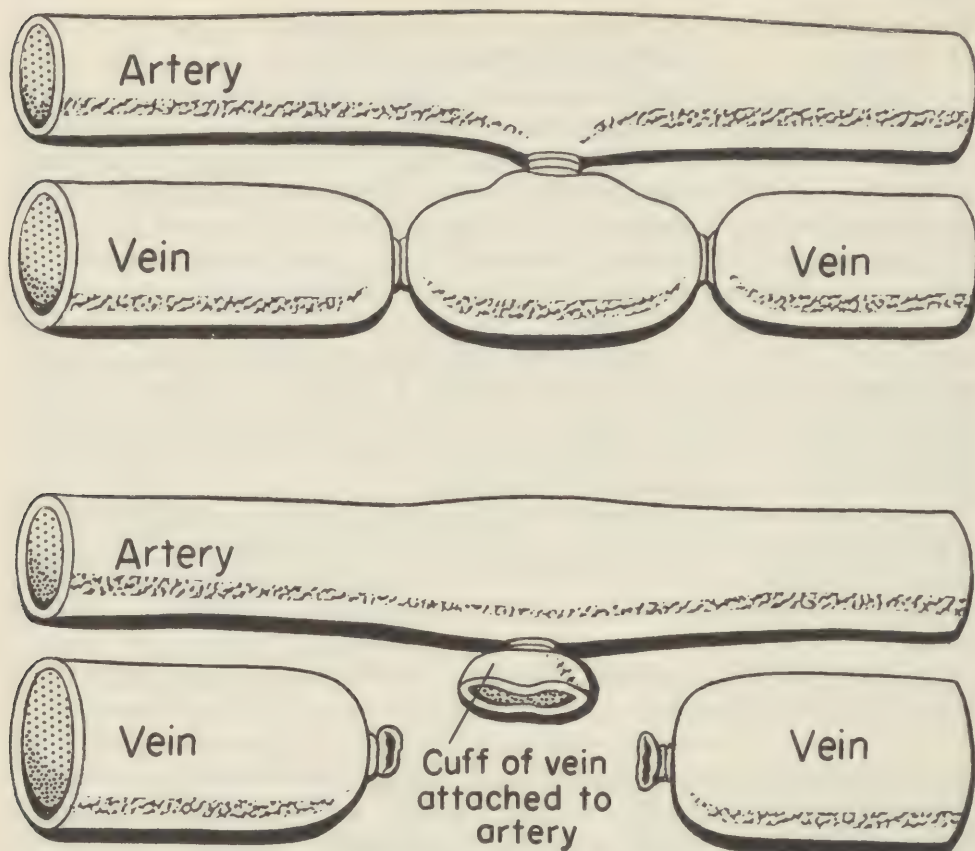


Figure 39. Ligation and transfixion of arteriovenous fistula. Top. The fistula has been ligated at its origin from the artery. A transfixing suture is next placed. Bottom. The vein has been divided above and below the fistula and the ends have been transfixed. The cuff of vein will now be plicated in order to reinforce the ligated fistula.

Lateral Arteriorrhaphy

There were 5 patients in which the arterial defect was repaired by lateral suture; of these, 2 exhibited aneurysms and 3, arteriovenous fistulas. (Table 30.) The age range in this group was from 20 to 29 years. Duration of the lesion at the time of operation ranged from 2.5 to 6.5 months. The brachial artery was affected in 1 patient, and the subclavian and the femoral artery in 2 patients each. There were no associated injuries.

Heparin was given in 3 patients, in 1 (Case 14) for 48 hours and in the others (Cases 15 and 17) until dicumarol had become effective. In the latter, dicumarol was continued for 11 days. Sympathectomy was not regarded as necessary in any patient in this group.

TABLE 30. LATERAL ARTERIORRHAPHY—DATA ON 5 PATIENTS WITH ANEURYSMS AND ARTERIOVENOUS FISTULAS

Case No.	Age of patient	Type of lesion	Location of lesion	Duration of lesion	Preoperative sympathectomy	Anticoagulant therapy	Length of arterial defect	Post-operative observations	Results
14	27	Saccular aneurysm.	Brachial, distal 3d.	Months 2.5	0	+	Mm. 4-5	Months 2.0	Excellent until hemorrhage 13th day. Secondary excision and ligation, good results. Gross infection present at first operation.
15	25	Saccular aneurysm.	Subclavian, distal 3d.	3.5	0	+	3	2.5	Excellent. Hematoma evacuated 10th postoperative day.
16	20	Arteriovenous fistula.	Subclavian, distal 3d.	6.0	0	0	12	1.5	Excellent.
17	27	Arteriovenous fistula.	Femoral, proximal 3d.	6.0	0	+	12	1.5	Excellent.
18	29	Arteriovenous fistula.	Femoral, middle 3d.	6.5	0	0	12	1.0	Poor. No pulse felt distally after operation. Excision of thrombosed segment 3 hours after first operation, good results.

The same basic technique was used on all patients (Fig. 40). The edges of the rent, after being freshened, were stripped of adventitia and approximated with interrupted mattress sutures. In the 3 arteriovenous fistulas the cuff of vein which remained was used to reinforce the closure.

Results in 3 patients were excellent. At the conclusion of the operation the diameter of the artery, which was in good condition in 2 patients and in fair condition in 1, was but slightly reduced. The color and warmth of the affected and nonaffected limbs were the same, as were the pulses. In the 2 patients in which oscillometric studies were made, the oscillations were bilaterally equal in 1; in the other, moderately reduced on the affected side.

In 2 patients the operation was a failure. In the first patient (Case 14), although the artery appeared in good condition, gross infection was present at operation. The arterial diameter was reduced only slightly at the conclusion of the procedure and continuity of blood flow was maintained, but on the 13th day after operation serious hemorrhage occurred through the sutured defect. Exploration showed no evidence of healing at the line of suture. The affected segment was therefore excised and the artery ligated. Results of this procedure were good. In the second patient (Case 18), the artery was in poor condition at operation and its diameter was reduced more than 50 percent by the surgical procedure. At this time the question arose whether immediate excision of the damaged segment might not be the wiser course. No pulse could be felt distally after operation and within 3 hours it was evident that thrombosis had occurred. The wound was reopened and the diagnosis verified, though neither central nor

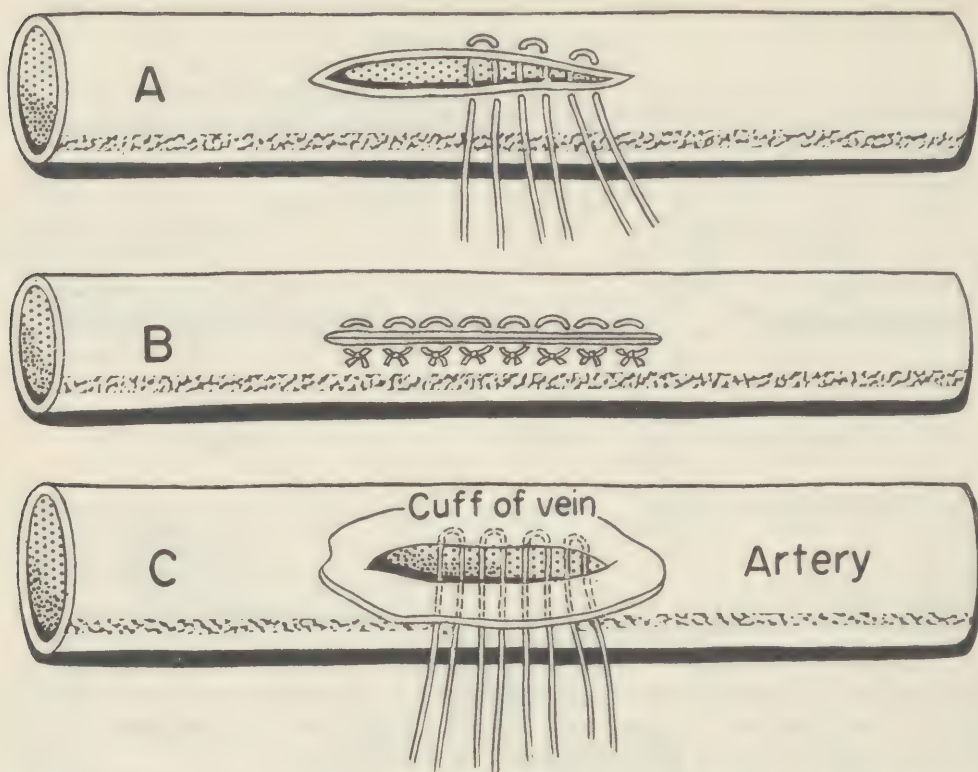


Figure 40. Lateral arteriorrhaphy. A, B. Lateral closure with interrupted everting mattress sutures. C. Application of the same technique to an arteriovenous fistula. A cuff of vein is left attached. After completion of the suture line, the venous cuff is closed with interrupted sutures.

peripheral propagation of the thrombus had occurred. The thrombosed segment was excised and recovery was thereafter uneventful.

End-to-End Suture

There were 10 patients in whom the artery was repaired by end-to-end suture; 8 were instances of aneurysm and 2 of arteriovenous fistula. (Table 31.) In 1 of the fistulas a saccular aneurysm was also present. The age range in this group was from 19 to 35 years and the duration of the lesion at the time of operation, from 3 to 8.5 months. The brachial artery was involved in 7 patients and the axillary artery in 2. In the remaining patient a double fistula was present between the femoral vein and the femoral and profunda femoris arteries. Five patients had injuries of the peripheral nerves; these injuries required neurolysis in all and neurorrhaphy in 2.

In 1 patient sympathectomy was performed before operation, and in all anticoagulant therapy was administered. In 1 patient receiving anti-

TABLE 31. END-TO-END SUTURE—DATA ON 10 PATIENTS WITH ARTERIAL ANEURYSMS AND ARTERIOVENOUS FISTULAS

Case No.	Age of patient	Type of lesion	Location of lesion		Dura- tion of lesion	Pre- opera- tive sym- path- ectomy	Anti- coagu- lant ther- apy	Length of ex- cised artery	Post- opera- tive obser- vations	Results
					<i>Months</i>			<i>Mm.</i>	<i>Months</i>	
19	20	Saccular aneurysm.	Brachial,	distal	5.5	0	+	1.5	2.0	Excellent.
20	35	Saccular aneurysm.	Brachial,	distal	7.5	0	+	1.5-2.0	2.0	Excellent.
21	27	Saccular aneurysm.	Brachial,	proxi- mal	8.0	0	+	1.5-2.0	3.5	Excellent.
22	28	Saccular aneurysm.	Brachial,	middle	8.5	0	+	1.5	2.0	Excellent.
23	23	Saccular aneurysm.	Axillary,	distal	5.5	+	+	2.0-2.5	2.0	Excellent.
24	19	Saccular aneurysm.	Brachial,	middle	6.0	0	+	1.5	2.0	Excellent.
25	24	Saccular aneurysm.	Brachial,	distal	6.0	0	+	2.0	1.0	Segment thrombosed. Good circulation.
26	21	Saccular aneurysm.	Brachial,	distal	3.0	0	+	2.0	5.0	Probably thrombosed and recanalized. Good circulation.
27	29	A-V fistula and saccu- lar aneur- ysm.	Axillary,	distal	3.0	0	+	2.0	4.0	Excellent.
28	29	A-V fistula.	Femoral and pro- funda arteries, femoral vein.		3.0	0	+	¹ 3.0 ² 2.0	2.5	Excellent.

¹ Femoral artery.
² Profunda femoris artery.

coagulant therapy (Case 25) heparin was given at operation and also, by mistake, 1,500 mg. of dicumarol and 250 mg. of heparin during the course of the following 20 hours. When the error was discovered, anticoagulant therapy was discontinued and synthetic vitamin K was given at once. No hemorrhagic difficulties ensued.

Damage to the involved arteries required the excision of segments ranging from 1.5 to 3.0 cm. in length. End-to-end suture was accomplished by first placing four evenly spaced mattress sutures which were used as traction sutures. This technique facilitated the insertion of the everting mattress sutures which completed the anastomosis (Fig. 41). In lesions of the axillary and brachial vessels, the length of the available artery was increased by ad-ducting the arm against the body and flexing the forearm upon the arm. This position was maintained after operation by the use of elastic bandages or plaster splints. In the patient in whom the femoral artery and the profunda were involved (Case 28), the divided ends of the femoral artery could not be approximated, but it was possible, without tension, to approximate the proximal end of the profunda to the distal stump of the femoral artery (Fig. 42).

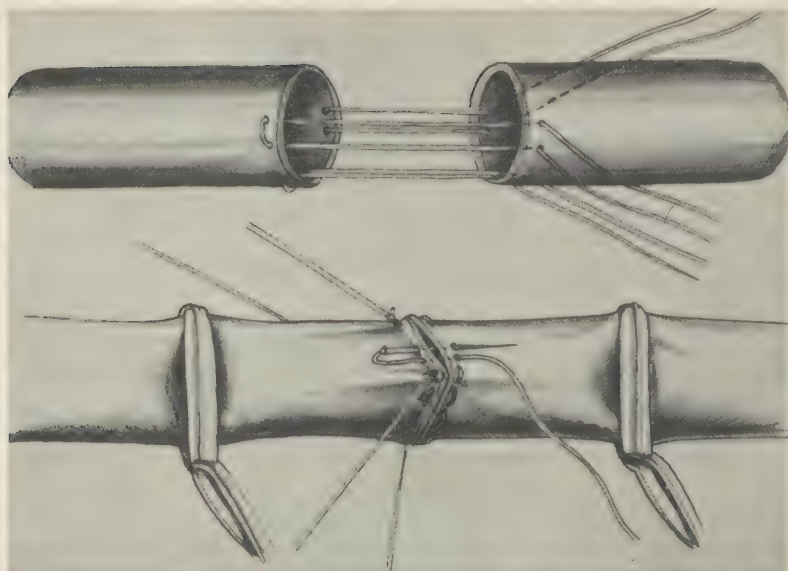


Figure 41. End-to-end suture. Four mattress sutures are placed through the ends of the vessels at equidistant points. Traction upon these sutures converts the cylindrical ends of the vessels into a square with the intima everted. Closure is completed with additional mattress sutures.

Good results were obtained in 8 of the 10 patients managed by end-to-end suture, but operation was unsuccessful in the other 2 patients. In 1 patient (Case 25), although good circulation was maintained in the hand, thrombosis of the sutured segment soon became evident. In this patient the aneurysm was near the distal end of the brachial artery, the sac lying partly in the belly and tendon of the biceps muscle. The divided ends of the artery could be sutured after the sac had been excised, but the diameter of the vessel was small and the distal segment was somewhat scarred as the result of the original trauma. Additional resection at this end to make more normal tissue available for suture would have been desirable, but this was impractical because of the proximity of the bifurcation of the vessel. In the other failure (Case 26) damage to the distal arterial segment was probably even more extensive than in the case just described. Though the patient continued to have a good radial pulse after operation, the ulnar pulsations were significantly reduced as were the oscillometric readings. The anastomosis may have remained patent, but it seemed more reasonable to assume that thrombosis had occurred and had perhaps been followed by recanalization.

Vein Transplant

There were 6 patients, 3 instances of aneurysm, 3 of arteriovenous fistula, in whom an arterial defect was repaired by vein transplantation. In 1 of the fistulas a saccular aneurysm was also present. In 5 of the patients the lesion



Figure 42. (Case 28, Table 31.) Postoperative arteriogram taken 10 weeks after resection of fistula between femoral and profunda femoris arteries and femoral vein, with end-to-end suture of profunda artery proximally to femoral artery distally. Injection of 70 percent diodrast into the common femoral artery reveals excellent filling of the femoral artery. No narrowing is evident at the suture line.

was of traumatic origin, in the sixth patient (Case 32) a saccular popliteal aneurysm had followed medionecrosis of the artery. The age range in this group was from 19 to 36 years and the duration of the lesion at the time of operation, in the 5 patients in which this information was available, ranged from 4 to 5.5 months in 4 patients. For the fifth patient it was 6 years. The

TABLE 32. VEIN TRANSPLANT—DATA ON 6 PATIENTS WITH ARTERIAL ANEURYSMS AND ARTERIOVENOUS FISTULAS

Case No.	Age of patient	Type of lesion	Location of lesion	Duration of lesion	Preoperative sympathectomy	Anticoagulant therapy	Length of vein graft	Source of vein graft	Post-operative observations	Results
20	20	A-V fistula and saccular aneurysm.	Femoral, distal 3d.	Months 4.0	0	+	Cm. 2.0	Saphenous	Months 3.0	Excellent.
30	19	A-V fistula.	Femoral, middle 3d.	5.0	0	+	2.0	Branch of femoral.	3.0	Excellent.
31	26	A-V fistula.	Femoral, distal 3d.	4.0	+	+	5.0	Saphenous	3.0	Excellent.
32	35	Saccular aneurysm.	Popliteal, middle 3d.	Unknown	+	+	2.0	Small saphenous.	4.0	Excellent.
33	36	Saccular aneurysm.	Femoral, proximal 3d.	72.0	0	+	2.5	Femoral...	1.5	Excellent.
34	24	Saccular aneurysm.	Brachial, middle 3d.	5.5	0	+	2.5	Saphenous.	1.0	Thrombosis. Good circulation maintained.

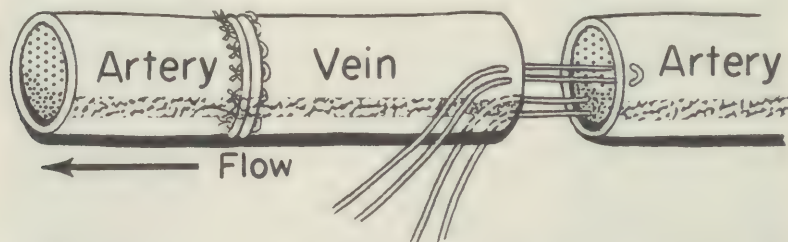


Figure 43. Vein transplantation. The venous segment has been sutured to the distal end of the artery with interrupted mattress sutures. Suture to the proximal end of the artery has been started.

femoral artery was involved in 4 patients and the brachial and the popliteal artery in 1 patient each. One patient had an associated fracture of the femur, and another a nerve injury for which neurolysis and neurorrhaphy were necessary.

All the patients in this group received anticoagulant therapy. In 2, sympathectomy was carried out.

The venous segment used for repair was excised from any accessible vein of suitable caliber. The main saphenous vein was used in 3 patients, and the femoral vein, a branch of the femoral vein, and the small saphenous vein in 1 patient each. The technique employed in end-to-end suture (that is, the use of mattress sutures as traction sutures before the other sutures are placed) was used in all 6 patients (Fig. 43). The segment of vein was so

inserted that its proximal end was sutured to the distal end of the artery and its distal end to the proximal end of the artery. This was done to inhibit the action of any valves which might be present in the transplanted segment.

Failure resulted in 1 patient (Case 34). Good circulation was maintained but thrombosis occurred. A possible explanation for this failure might be that the suture was technically imperfect because the brachial artery was unusually small. Excellent results were achieved in the other 5 patients. Arteriograms revealed patent vessels, and showed no postoperative dilatation of the venous insert. When the vessels were of approximately the same size, the relative diameters remained essentially unchanged. When the venous transplant had been larger than the artery at operation, it was found to have assumed much the same proportions as the artery.

Results

In general, the results of arterial repair were excellent. Twenty-eight reparative procedures out of a possible 34 were successful. Except for some edema in 2 of the patients listed in Table 29, a symptom which diminished progressively with the passage of time, the circulatory status appeared normal. None of the patients had sensitivity of the hand or foot to cold—a fairly common sequela in those in whom aneurysm or fistula was treated by a procedure involving ligation of the artery. Excluding a few patients in whom exercise tolerance could not be judged fairly because of motor paralysis or fracture, and a few who had fatigability of the extremity before operation at a time when blood flow through the affected artery was intact, none had any appreciable decrease in tolerance of exercise. This was in decided contrast to those in whom surgical treatment had necessitated ligation of a major artery. To illustrate, those with ligated popliteal or femoral arteries could walk only an average of about seven-tenths of a mile before onset of extreme fatigue or cramps in the calf.²³

In retrospect, of course, it becomes clear that certain of the failures might perhaps have been avoided if a different plan of treatment had been adopted, though in other instances no alternative method could conceivably have altered the outcome. In Case 13 (Table 29) the vein should have been divided and used to reinforce the transfixated fistula, the technique employed in the other 12 patients treated by this method. In Case 14 (Table 30) gross infection was present and it is not surprising that satisfactory healing did not occur. In Case 34 (Table 32) no technique other than vein transplantation could have been used for repair because of the length of the arterial segment which had to be excised. In this patient the vessel was unusually small and while it is possible that repair was not technically perfect, it appeared satisfactory at the time of operation and there was a free flow of blood through the venous insert when the incision was closed. In Cases 18 (Table 30), 25 and 26 (Table 31),

²³ Shumacker, H. B., Jr.: Sympathectomy as an adjuvant in the surgery of aneurysm and arteriovenous fistulas. *Surgery* 22: 571-596, Oct 1947.

local damage to the artery was sufficient to account for the postoperative thrombosis. In Case 18 lateral suture should probably not have been performed; it would have been better to excise the damaged segment and to accomplish repair by end-to-end suture or vein graft. Anticoagulants should also have been used. In Cases 25 and 26 additional resection of the distal segment was recognized as desirable, but was not possible because of the close proximity of the point of bifurcation of the vessel to the severed distal end. In Case 26 there was a difference of opinion about the end results. The operating surgeon believed that thrombosis and subsequent recanalization had occurred, but several other surgeons who examined the patient differed with him and regarded the operation as successful.

In addition to the complications just discussed there were a few others. One patient had a postoperative hematoma which required exploration of the wound 2 hours after the original operation (Case 30, Table 32). The vein graft was found to be functioning well and the bleeding to be coming from a small branch to a muscle. This was clamped and ligated. Three other patients had hematomas develop in the wound. (Case 15, Table 30, and Cases 32 and 33, Table 32.) In 1 instance the hematoma was evacuated by aspiration. In the other 2 instances exploration of the wound revealed diffuse capillary bleeding. All of these patients were receiving anticoagulant therapy and in each patient the therapy was stopped and no further difficulty encountered. In 2 patients (Cases 32 and 33, Table 32) mild wound infections developed, but did not interfere with the success of the vascular repair.

Methods of Evaluating Results

Various examinations were used to evaluate the success of the reparative operation in terms of patency of the repaired artery. That the foot was warm and of a healthy color was not considered sufficient evidence, nor was the presence of pulsations distal to the repair. The presence of a palpable radial pulse after brachial or axillary repair or of a dorsalis pedis pulse after femoral or popliteal repair was also not sufficient evidence since such pulses may be present after ligation of main arteries proximally if the collateral circulation is adequate. The presence of *all* pulses distal to the site of repair, if they were equal in volume to the pulses in the contralateral limb, was felt to provide adequate evidence of successful maintenance of continuity of the artery. When, for instance, full popliteal, posterior tibial, and dorsalis pedis pulses were present after repair of the femoral artery, the patency of the latter vessel could be assumed.

Arteriograms were of great value after operation to determine the patency of the repaired artery and to furnish evidence of dilatation or other changes which might result from arterial repair. In addition, criteria of success included oscillometric results comparable to those in patients in which the patency of the artery was established by arteriographic examination and in excess of those observed in proved instances of arterial ligation.

Data concerning oscillometric studies are available in 28 of the 34 patients in whom reparative surgery was carried out at Mayo General Hospital (Table 33). In 23 of these patients the operation was successful, in the other 5 patients either thrombosis occurred or ligation had to be done secondarily because of hemorrhage or recurrence of the fistula. In general, oscillometric readings were high in those patients in whom the continuity of blood flow through the repaired artery was maintained and low in those in whom the segment was occluded by thrombosis or the artery was ligated.

Of considerable interest was the observation that oscillations were, in general, about equal on both sides when the fistula was simply ligated and transfixed, were only slightly reduced on the affected side when lateral arteri-

TABLE 33. OSCILLOMETRIC STUDIES FOLLOWING ARTERIAL REPAIR IN 28 PATIENTS

Type of repair	Artery repaired	Number of patients	Oscillometric reading at ankle or wrist		Oscillometric reading at calf or forearm		Oscillometric reading at thigh or arm	
			Average reading	Percent of reading in contra-lateral limb	Average reading	Percent of reading in contra-lateral limb	Average reading	Percent of reading in contra-lateral limb
Ligation of fistula.....	Femoral.....	5	2.3	96	5.1	96	3.5	95
Ligation of fistula.....	Popliteal.....	4	5.1	75	7.6	95	-----	0
Lateral arteriorrhaphy.....	Subclavian.....	2	2.5	83	3.8	70	4.5	88
End-to-end suture.....	Axillary.....	2	1.0	37	1.5	41	2.2	44
End-to-end suture.....	Brachial.....	4	2.5	83	2.8	51	-----	0
End-to-end suture.....	Femoral.....	1	3.0	70	4.5	50	7.0	100
Vein transplantation.....	Femoral.....	1	3.1	67	4.0	50	4.0	67
Vein transplantation.....	Popliteal.....	1	2.0	67	3.0	43	-----	0
Total successful cases.....	-----	23	2.9	79	4.3	68	4.0	68
Unsuccessful cases*.....	-----	5	1.0	17	0.9	16	0.5	18

*These 5 cases included 1 lesion involving the femoral and 4 involving the brachial artery.

orrhaphy was performed, but were reduced to a somewhat greater degree in those patients in whom end-to-end suture or vein graft was done. This observation came as a surprise since in all of these patients comparison of the color, warmth, and pulsations in the normal and in the affected limb were substantially the same after reparative surgery. The reduction in oscillations did not seem explicable on a basis of local or general vasoconstriction, since the limbs showed no evidence of vasospasm. Moreover, in some patients in whom sympathectomy had been performed a similar reduction in oscillations was noted. Arteriograms showed no evidence of constriction at the site of repair. Since there was little or no evidence of any functional circulatory impairment, the diminished oscillations were considered of little practical concern.

SUMMARY

The ideal method for the surgical treatment of aneurysms and arteriovenous fistulas is extirpation of the lesion and maintenance or restoration of the continuity of the artery. Though local anatomic factors sometimes preclude the use of reparative methods, the attitude of the surgeon determines, perhaps more than anything else, the frequency with which these procedures are applied. A high degree of success can be expected; nevertheless, one cannot assume that the results of arterial repair will be uniformly successful. Since this is the case, it is advisable to do everything possible to make certain that the collateral circulation is adequate before definitive surgery is attempted.

The chief hazards of surgical repair of arteries are hemorrhage, thrombosis, and subsequent development of aneurysmal dilatation at the site of repair. The chief local factors which endanger the success of the repair appear to be damage to the wall of the artery, infection, or a lumen of such small caliber as to make accurate approximation difficult.

In the present series postoperative hemorrhage occurred only once; the sutured artery lay in a pool of pus and healing did not take place. Thrombosis occurred 4 times; 3 times following lateral arteriorrhaphy or end-to-end suture in which local arterial damage was sufficiently extensive to raise doubts in the mind of the surgeon at the time of the operation that the artery would remain patent. In the other instance an exceedingly small brachial artery was repaired with a vein transplant.

Extension of a thrombus so as to compromise important collateral arteries has been advanced as contraindicating arterial repair. The data from this series suggest that such propagation of a thrombus is unlikely provided the collateral circulation is adequate, for extension of a thrombus is not apt to occur if the circulation proximal and distal to the site of repair is kept active by collateral blood flow. In one patient in whom thrombosis occurred, the occluded segment was excised and the thrombus sharply limited to the immediate area of repair. Furthermore, the chance of thrombosis occurring, or of its propagation if it should occur, can be lessened considerably by the use of anticoagulants.

There was recurrence of an arteriovenous fistula in one patient in this series—the fistula was simply transfixated and ligated in continuity, a procedure which appears to be unwise. No aneurysms developed at the site of repair in any instance. Should this unfortunate event take place it appears likely that it would occur within the first few weeks or months after operation and not years later when atherosclerotic changes might add an additional hazard to its extirpation. Under such circumstances it would seem that the original procedure could still be looked upon as justifiable; such patients should be able to withstand surgical cure of the aneurysm with no more risk than would have been entailed had the artery been ligated at the original operation.

It was the opinion at this center that while the patient may have been subjected to certain additional hazards, these hazards are minimal and of little practical concern provided the collateral circulation is adequate, no collateral vessels are sacrificed, and anticoagulants are used. Altogether there seems every justification for performing reparative or restorative procedures instead of arterial ligation whenever such methods can be applied. Certainly the results of successful repair are superior to those of any method which necessitates sacrificing the continuity of the affected artery.

CHAPTER IX

Arterial Aneurysms and Arteriovenous Fistulas Successful Suture of the Abdominal Aorta for Arteriovenous Fistula

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and

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An arteriovenous fistula involving the abdominal aorta is seldom observed since death usually follows promptly from the massive hemorrhage caused by the original injury. Even if the patient recovers from the initial loss of blood, as in the two cases reported by Makins¹ in which the patients survived for several weeks, the short-circuiting of the circulation immediately places such a strain on the heart that early cardiac failure occurs.

In 1944, Pemberton, Seefeld, and Barker² successfully repaired an arteriovenous fistula occurring between the abdominal aorta and the inferior vena cava. They were unable, in a comprehensive review of the literature, to find any previously reported case in which the patient had survived for a sufficiently long period of time after surgical repair to furnish evidence that the operation had been successful. The case described in this chapter is apparently the second to be recorded in which a successful repair of the abdominal aorta has been performed.

CASE REPORT

The patient, a 25-year-old infantryman, was wounded on Okinawa 14 May 1945. A bullet from a .25-caliber rifle entered the abdomen 3 inches below the ensiform cartilage just to the right of the midline and passed out through the back at the level of the second lumbar vertebra. He immediately became paralyzed below the waist. A laparotomy was performed the day of injury and a large retroperitoneal hematoma found. The abdomen was closed without drainage. The patient stated that he was told that numerous veins had been tied off during the operation. Ten days after injury he was transferred to another hospital where roentgenograms were made. They disclosed several fracture lines in the spinous process of the second lumbar vertebra radiating through the lamina without displacement or separation. On the 15th day after injury, a laminectomy was performed and the comminuted fragments of the spine at the first and second lumbar vertebrae, and the lamina of the second lumbar vertebra, removed. The underlying dura was found to be compressed and lacerated and three of the nerve roots severed.

¹ Makins, G. H.: On Gunshot Injuries to the Blood Vessels, Founded on Experience Gained in France During the Great War, 1914-1918. Bristol, John Wright & Sons, Ltd., 1919.

² Pemberton, J. deJ.; Seefeld, P. H., and Barker, N. W.: Traumatic arteriovenous fistula involving the abdominal aorta and the inferior vena cava. *Ann. Surg.* 123: 580-590, Apr 1946.

After this operation there was considerable return of function in the lower extremities. On the fifth postoperative day, swelling of the right leg appeared and a diagnosis of thrombophlebitis was made. This swelling subsided in a few days.

Preoperative Clinical Course. Six weeks after his original injury the patient complained of some epigastric pain and, on examination, a pulsating mass with intense thrill was found in the upper abdomen. A diagnosis of aneurysm of the abdominal aorta was made and he was evacuated to the Zone of Interior.

When admitted to the debarkation hospital his blood pressure was 150 mm. of mercury systolic and 60 diastolic. Hemaglobin was 72 percent of normal and urine examinations showed some infection to be present. Tidal drainage was instituted to correct this condition. Some dilated veins over the abdominal wall were observed. Physical examination revealed nothing which would indicate cardiac enlargement. That the heart was of normal size was confirmed by roentgenogram. A chemical examination of the blood revealed it to be essentially normal, and the result of the Kahn test was negative.

The patient was transferred to the vascular center at DeWitt General Hospital 3 August 1945. Examination at this time revealed a pulsating mass in the epigastrium which was more prominent on the right of the midline. The superficial abdominal veins were dilated (Fig. 44).

A continuous loud bruit, which was accentuated during systole, could be heard over the mass in the abdomen. The pulse rate was 96 beats per minute and the blood pressure 152 mm. of mercury systolic and 96 diastolic. The heart was not enlarged and there was no



Figure 44. Infrared photograph of patient with arteriovenous fistula involving abdominal aorta and vena cava. Note dilatation of veins of abdomen and thorax.

evidence of dilatation or engorgement of the neck veins. The patient was neither dyspneic nor orthopneic. Venous pressure measured in the right antecubital vein was 3 cm. of water. The lungs were clear and the liver edge palpable at the right costal margin.

Neurologic examination revealed a residual paraplegia involving principally the motor components of the posterior tibial and common peroneal nerves on the right side, and some involvement of the peroneal nerve on the left side. The sensory loss was small and was confined to a small area about the anus and scrotum on the right side.

It was not possible to obliterate the thrill by pressure in the epigastrium or right upper quadrant. The fact that the heart showed no evidence of marked strain, even 3 months after the development of the lesion, was interpreted as evidence that there was some interference with the free return of blood from the arterial to the venous side of the circulation. Since the liver was not enlarged, it was felt that there was no involvement of the portal venous system. The dilatation of the superficial abdominal veins suggested involvement of the inferior vena cava. A diagnosis was made of arteriovenous fistula probably involving a branch of the abdominal aorta and either the vena cava or some tributary of this vein.

The patient was placed on the paraplegic ward where he was encouraged to increase his activities as much as was compatible with his residual neurologic lesions. During his stay the bladder infection was controlled by tidal drainage, his appetite improved, and he regained some of the weight which he had lost.

On 15 September, 4 months after the initial injury, the patient complained of some abdominal discomfort and vomited. Examination at this time disclosed the abdominal mass to be approximately 6 cm. in diameter. Both the pulsation and the thrill were more apparent than they had been. Gastrointestinal examination with a barium meal failed to reveal evidence of any extrinsic mass producing pressure upon the pylorus or duodenum. The cardiac consultant noted a definite increase in the size of the liver with an increase in the pulse rate and expressed the opinion that the patient was showing evidence of cardiac strain. Because of the possibility of cardiac damage and the increase in the size of the mass it was decided to operate without further delay.

Operation. The operation was carried out with the patient under intratracheal ether-oxygen anesthesia. A right paramedian incision was made from the xyphoid to just below the umbilicus. Numerous dilated veins were encountered in the subcutaneous tissues. When the peritoneum was opened, a large pulsating mass was found beneath the gastrohepatic omentum. A puckered scar was present near the border of the liver on the right side and probably represented the point of entrance of the rifle bullet. The aneurysm, which lay behind the vena cava, displaced the vena cava forward and so compressed it as to hinder the ready flow of blood back to the right side of the heart. The veins of the portal system did not appear to be dilated. The hepatic, common, and cystic ducts were readily visualized and appeared to be pushed forward by the pulsating mass which occupied the posterior aspect of the right upper quadrant. The aneurysm was under considerable pressure and at one point, below and slightly medial to the gallbladder, the thrill of the arteriovenous fistula was most easily palpable. While compression at this point obliterated the thrill, it also appeared to produce an increase in the intra-aneurysmal pressure.

The round ligament of the liver and some adhesions were divided. An attempt was made to visualize the artery entering the aneurysm by dividing the gastrohepatic omentum. This, however, still did not permit localization of the opening of the artery into the aneurysm. Only by pressure on the aorta at the hiatus of the diaphragm was it possible both to obliterate the thrill and to cause the aneurysmal sac to collapse. The aorta was therefore exposed at this point by dividing some of the fibers of the diaphragm. It was then encircled by a fine rubber catheter fitted to a Bethune tourniquet. Attempts to expose the aorta through the root of the mesentery beneath the transverse colon were unsuccessful because of the dilated veins in this region.

The peritoneum and transversalis fascia were next incised from within the abdomen just to the left of the midline. By separating these structures from the underlying muscles

it was possible to expose the anterior surface of the psoas muscle and the vertebral column. The spleen, descending colon, pancreas, left kidney, and intestines were reflected to the right and the abdominal aorta exposed as it lay on the anterior surface of the lumbar vertebrae. Many large veins were divided and ligated. The tissues about the aorta were thickened and edematous. The discoloration which was present indicated old hemorrhage. The abdominal aorta was encircled by a segment of rubber tubing just proximal to the origin of the inferior mesenteric artery. It was then exposed just above the origin of the left renal artery where it was again encircled by a piece of tubing. Compression of the aorta by this piece of tubing caused the sac to collapse. An additional section of tubing was placed about the left renal artery. With the proximal and distal aorta and the left renal artery occluded, the inflammatory tissues surrounding the aorta at the site of the fistula were incised and the aorta was finally cut away from the aneurysm at this location. Figure 45 illustrates the location of the lesion.

The opening into the aorta measured one-half inch in length. It was closed by a transverse running stitch of No. 0000 Deknatel which had been passed through sterile mineral oil. Bleeding from the sac was only moderate and was readily controlled by digital pressure. No effort was made to excise the sac. This opening was closed by a running stitch of No. 0000 silk. At the conclusion of this procedure, the segments of tubing around the distal aorta, left renal artery, and proximal aorta were released in that order. Good pulsation, expansile in character, was apparent in the aorta below the suture line. No bleeding took place. Two Penrose drains were inserted through a stab wound below the left costal margin into the region of the left lumbar gutter and the abdomen was closed.

During the operation, which lasted almost 8 hours, the patient received a continuous transfusion of 3,000 cc. of whole blood and 500 cc. of physiologic salt solution. When the abdominal aorta was occluded the blood pressure increased from 118 mm. of mercury systolic and 70 diastolic to 240 systolic and 100 diastolic. The pulse rate rose from 130 to 160 beats per minute and the neck veins became greatly distended. When the tourniquet, which had been in place for 1 hour and 40 minutes was released, the systolic pressure fell to 50 mm. of mercury. Within 30 minutes, however, it rose to 110 mm. of mercury. The diastolic pressure at this time was 80 and the pulse rate was 140 beats per minute.

Postoperative Course. Immediately after operation a strong femoral pulse was palpable and within an hour the pulse at the wrist was of good volume and all extremities warm and dry. The patient was placed in an oxygen tent and continuous intestinal decompression therapy was instituted by means of suction applied to an indwelling Levin tube. By the following morning the abdomen was flat and peristalsis present. The patient was conscious and alert. Because of persistent low blood pressure and a rapid, weak pulse, he was given another transfusion of whole blood. Blood pressure then rose to 160 mm. of mercury systolic and 90 diastolic. Administration of penicillin and sulfadiazine was begun, but owing to urinary suppression the sulfadiazine was discontinued after the administration of 7 gm. in the first 36 hours.

Impaired renal function presented a serious complication. During the first 48 hours, in spite of receiving 3,500 cc. of 5-percent glucose in distilled water and 1,000 cc. of 5-percent glucose in physiologic salt solution, the patient voided only 200 cc. of urine. Elevation of the nonprotein nitrogen following operation is shown in Table 34.

For the first week after operation treatment consisted chiefly of continuous oxygen therapy, decompression of the upper gastrointestinal tract, and the administration of fluids by vein in amounts just sufficient to balance the losses through the gastrointestinal tract and kidneys, and by insensible loss of water.

Three days after operation the venous pressure in the right antecubital vein was 12.6 cm. of saline solution. The patient was feeling well, but he had no appetite and his mouth was sore because of superficial erosions of the mouth and lips. Blood pressure was consistently 170 mm. of mercury systolic and 80 diastolic.

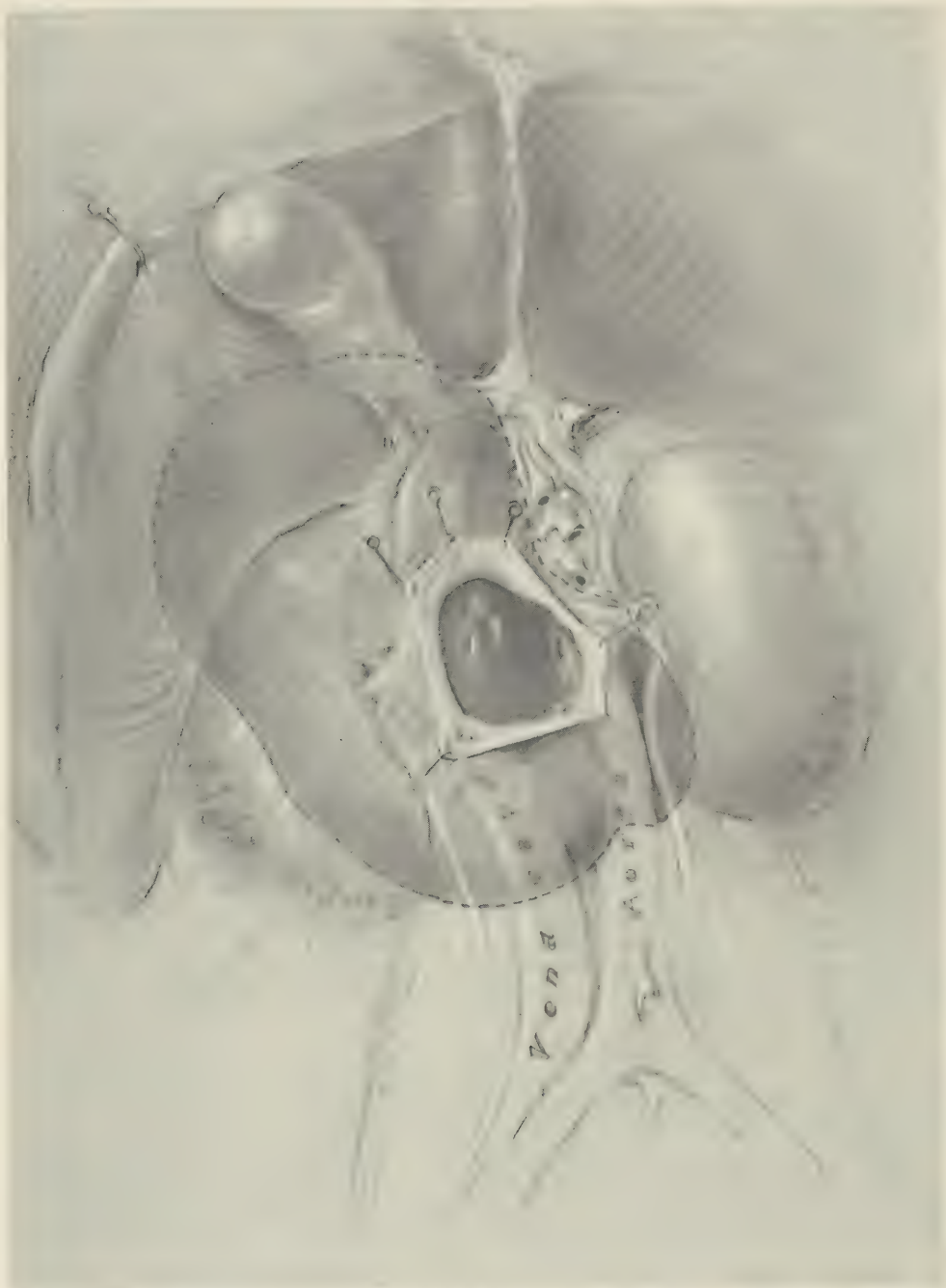


Figure 45. Diagrammatic representation of findings at operation for arteriovenous fistula of abdominal aorta and vena cava.

TABLE 34. CHEMICAL CONSTITUENTS OF BLOOD

Date of determination	Nonprotein nitrogen	Urea nitrogen	Chlorides	Serum proteins	CO ₂ Combining power
	<i>Mg. per 100 cc.</i>	<i>Mg. per 100 cc.</i>	<i>Mg. per 100 cc.</i>	<i>Gm. per 100 cc.</i>	<i>Vol. %</i>
27 July-----	33. 7				
14 August-----	34. 0	18. 7		7. 10	
27 September-----	Operation				
29 September-----	111. 6		522	6. 48	60. 4
30 September-----	116. 0				
1 October-----	116. 0	80. 9	541	5. 39	
3 October-----	120. 0	91. 0	591	5. 75	
5 October-----	107. 0		572	6. 48	59. 3
9 October-----	70. 5		568		61. 9
13 October-----	63. 1				

Six days after operation, ophthalmologic examination was reported as showing "remarkable generalized narrowing of the retinal arterioles throughout all divisions. In many of the vessels there are variations in caliber indicative of focal spasm. No signs of sclerosis are noted, no hemorrhages or edema." A diagnosis of acute retinal angiospasm was made.

Because of his sore mouth and lack of appetite the patient refused to eat. On the 10th postoperative day, therefore, high caloric feedings were started. In 36 hours the patient received 1,500 cc. of fluid containing approximately 1,800 calories. The feedings were given by continuous drip through a nasal tube. He tolerated this feeding very well and his general condition improved rapidly. The nonprotein nitrogen of the blood dropped as the volume of urinary excretion increased. The wound healed without complications.

The day after operation the patient noted that he could not dorsiflex the left foot. Neurologic examination showed a definite increase in the neurologic disturbances noted prior to operation. In addition to the foot drop on the left side, the area of anesthesia had increased and there was a decrease in the bladder tone. For the first 2 months after operation severe burning pain was experienced in both feet, but this condition suddenly cleared up at the end of this period with a concurrent improvement in motor power.

Evidence of renal damage persisted for several weeks with a constantly low specific gravity of the urine and persistent mild hypertension, and even 6 weeks after operation the ophthalmologic examination revealed moderate generalized narrowing and increased tortuosity of the retinal vessels. Excretory urograms made 6 weeks after operation revealed the excretory function of the kidneys to be normal. The final urine concentration test, made 2 months after operation, showed an ability of the kidneys to concentrate the urine to 1.018. Roentgenograms, made at this time, showed a defect in the laminae between the second and third lumbar vertebrae at the site of the original fracture.

About 2½ months after operation the patient was transferred to another general hospital. At this time he had recovered sufficiently from the spinal cord injury to walk with the aid of one cane.

Eight months after operation it was reported that the patient had shown no evidence of recurrence of the fistula.

COMMENT

The presence of a fistula between the abdominal aorta and vena cava usually leads to rapid heart failure and death. The absence of this complication in this case can probably be explained by the intervention of a large

aneurysmal sac between the two vessels. The dilatation of the superficial abdominal veins observed before operation is in keeping with this explanation. The transient swelling of the right leg noted 10 days after injury (which was originally diagnosed as thrombophlebitis) was probably the result of interference with the return flow of blood from the lower extremity.

The increase in the paralysis of the bladder and lower extremities following operation was not surprising in view of the fact that the abdominal aorta was completely occluded for 100 minutes. After complete occlusion of the aorta for a period of 40 to 55 minutes, Blalock and Park³ observed paralysis of the hind quarters in the dogs used in their experiments. The neural damage evident after operation might be attributed to the result of impairment of the circulation to the spinal cord and cauda equina or to the temporary ischemia of the distal nerves, but the involvement of the nerves to the bladder suggest the former explanation. The rapid improvement which was observed 2 months after operation indicated a favorable prognosis.⁴

The second postoperative complication was the temporary urinary suppression, associated with hypertension. This complication was probably the result of the renal ischemia produced by occlusion of the abdominal aorta above the renal arteries. It was associated with marked vasospastic changes in the eye-grounds and with nitrogen retention. With resumption of renal function at the end of 2 weeks, the hypertension subsided. The final urine concentration test, which was done 2 months after operation, showed an ability to concentrate to 1.018. The excretory urogram was also quite satisfactory, but it is possible that some permanent damage to the kidneys was sustained. In a case reported by Alexander and Byron⁵ in which a segment of the thoracic aorta was resected, hypertension with severe retinal angiospasm, exudates, and hemorrhages proved a serious late complication. In a case reported by Pemberton, Seefeld, and Barker,⁶ persistent hypertension with cardiac hypertrophy was also noted.

During the operation considerable difficulty was experienced in locating the opening of the artery into the aneurysmal sac. Reflection of the duodenum with exposure of the anterior surfaces of the aorta and vena cava was employed by Pemberton and his associates⁷ as the method of exposure, but the aneurysmal sac in their patient lay to the left of the aorta. Since in this case the sac appeared to lie between the aorta and the vena cava, a similar approach could not be used. It was only after retroperitoneal exposure of the anterior surface of the psoas muscle and the lumbar vertebrae by displacement of the abdominal

³ Blalock, A., and Park, E. A.: Surgical treatment of experimental coarctation (atresia) of the aorta. *Ann. Surg.* 119: 445-456, Mar 1944.

⁴ When this patient was examined a year after the operation at the time of his discharge from the Veterans Hospital at Van Nuys, Calif., he could walk with the aid of a single cane and could go up and down stairs. There was no recurrence of the abdominal aneurysm or arteriovenous fistula. Bladder control was incomplete, but he could retain 12 oz. of urine. Subsequently a letter was received from the patient saying that he had returned to work (cabinetmaking) and was able to hold a full-time job.

⁵ Alexander, J., and Byron, F. X.: Aortectomy for thoracic aneurysm. *J. A. M. A.* 126: 1139-1145, 30 Dec 44.

⁶ See footnote 2, p. 302.

⁷ *Ibid.*

contents from the left lumbar gutter that the abdominal aorta could readily be exposed. It was then possible to visualize the entire length of this vessel from the diaphragm to its bifurcation.

Transvenous suture of the opening between the aorta and vena cava, the technique known as the Matas-Bickham⁸ operation, was used by Pemberton and his associates. Although it is frequently valuable, it has the disadvantage of not permitting inspection of the entire arterial wall and arterial aneurysms have been known to develop after its use in cases in which there happened to be additional weakened points in the arterial wall. Closure of an arteriovenous fistula leads to a marked increase in blood pressure within the artery at the site of the fistula.⁹ If the wall close to the former communication is defective it may give way and result in the formation of an aneurysm. On the other hand, complete dissection of the artery from the fistula permits thorough examination so that other damaged portions of the wall are unlikely to escape notice. Excision of the damaged portion of the arterial wall with transverse closure of the defect is the procedure of choice under these circumstances.¹⁰

⁸ Matas, R.: Treatment of arteriovenous aneurisms by intrasaccular method of suture (endo-aneurismorrhaphy) with special reference to transvenous route. *Ann. Surg.* 71: 403-427, Apr 1920.

⁹ Freeman, N. E.: Direct measurement of blood pressure within arterial aneurysms and arteriovenous fistulas. *Surgery* 21: 646-658, May 1947.

¹⁰ Freeman, N. E.: Arterial repair in the treatment of aneurysms and arteriovenous fistulae; report of 18 successful restorations. *Ann. Surg.* 124: 888-919, Nov 1946.

CHAPTER X

Arterial Aneurysms and Arteriovenous Fistulas Anticoagulant Therapy in Reparative Surgery

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and

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Prior to World War II occasional reports appeared in the literature concerning the clinical and experimental use of anticoagulants in arterial surgery. All, however, were limited to the use of heparin.¹ The anticoagulant dicumarol was not introduced until after the beginning of the war.² While these two agents were not generally used in the vascular centers at the general hospitals in the Zone of Interior, they were employed occasionally on special indications at some of the centers. At Mayo General Hospital where they were used, a study was undertaken to test their efficacy in the prevention of thrombosis following arterial repair. The patients chosen for this study were those in whom some type of reparative or restorative procedure had been employed in an effort to maintain continuity of the artery following surgical obliteration of a peripheral aneurysm or arteriovenous fistula.

CLINICAL MATERIAL AND METHODS

Some type of reparative surgery (transfixion of fistula, lateral arteriorrhaphy, end-to-end suture, or vein transplantation) was carried out in 34 patients in a series of 288 aneurysms or arteriovenous fistulas treated at this installation. Twenty-two of these 34 patients received anticoagulant therapy for a more or less prolonged period of time. An additional patient received a single injection of heparin at the time of operation. Eighteen received combined heparin-dicumarol therapy after operation, 2 received dicumarol before operation and combined therapy afterward, 2 received only dicumarol which was given both before and after operation. In these 23 patients there were 3 instances of postoperative thrombosis.

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¹ (1) Murray, G. D. W.: Heparin in surgical treatment of blood vessels. *Arch. Surg.* 40: 307-325, Feb 1940.

(2) Murray, G. D. W.: Heparin in thrombosis and blood vessel surgery. *Surg., Gynec. & Obst.* 72: 340-344, Feb 1941.

² Link, K. P.: The anticoagulant from spoiled sweet clover hay. *Harvey Lecture Series* 39: 162-216, 1943-44.

Of these 34 patients treated by reparative arterial surgery, 11 did not receive anticoagulant therapy. In 1 of these patients postoperative thrombosis occurred.

In the majority of patients in this series, heparin was administered on the operating table as soon as the decision was made to attempt arterial repair and was continued for a period of hours until dicumarol, administration of which had been begun as soon after operation as the prothrombin time could be determined, had produced a satisfactory alteration of the prothrombin level.

Crystalline heparin in aqueous solution was given intravenously in 50-mg. doses every 4 hours for a period of 48 hours. During this time its anticoagulant effect was measured occasionally, but not at regular intervals, by determining the clotting time according to the method of Lee and White.³

The method of Quick⁴ was used for the determination of the prothrombin level. In general, 300 mg. of dicumarol were given the first day, 200 mg. the second day, and 100 mg. the third day. Thereafter the dosage for each patient was determined daily on the basis of the level of his prothrombin time. The exact quantity required to maintain the prothrombin time at the desired level varied for the different patients and not infrequently for the same patient during the course of therapy. Generally a daily dose of 100 mg. was necessary, although in some instances smaller amounts were adequate. When a patient was being given heparin and dicumarol concurrently, blood for prothrombin determinations was drawn just before the administration of a dose of heparin in order to minimize any possible effect of the latter upon the prothrombin blood level determination. An effort was made to maintain the prothrombin level in the neighborhood of 20 to 30 percent of normal according to the Quick curve;⁵ this is roughly equivalent to a "clotting index" of 50. A control test using normal plasma was run with each daily set of determinations.

It was found to be a wise precaution to delegate dicumarol therapy to a single member of the staff. Each morning a report of the prothrombin determinations of all patients receiving this therapy was submitted to the responsible staff member. On the basis of this information he issued orders regarding each patient's dosage of dicumarol for that day.

Eighteen patients in this series of 23 received combined heparin-dicumarol therapy after operation. In 1, ligation and transfixion of a fistula had been performed, in 3 lateral arteriorrhaphy, in 10 end-to-end suture, and in 4 vein transplantation. In these patients the administration of heparin was started during the operation procedure and continued for an average of 48 hours; dicumarol, which was administered as soon after operation as a prothrombin determination could be obtained, was usually continued for 21 days. In a few patients dicumarol was given for periods ranging from 10 to 16 days; in 4 patients it was given for even shorter periods of time.

³ Lee, R. I., and White, P. D.: A clinical study of coagulation time of blood. *Am. J. M. Sc.* 145: 495-503, 1913.

⁴ Quick, A. J.: Clinical application of hippuric acid and prothrombin tests. *Am. J. Clin. Path.* 10: 222-233, Mar 1940.

⁵ Quick, A. J.: Nature of bleeding in jaundice. *J. A. M. A.* 110: 1658-1662, 14 May 38.

In each of these 4 patients there was a special reason for discontinuing the therapy. In the first patient the response was unusually prompt and the prothrombin level at the end of 6 days abnormally low. In the second patient lateral suture had been performed in the presence of gross infection. Since the prognosis for healing was poor and hemorrhage a possibility, dicumarol was discontinued after the third day. In the third patient dicumarol was discontinued on the fourth day because of persistent bleeding from the wound. In the fourth patient, in which a brachial aneurysm was excised and end-to-end suture accomplished, the usual heparin-dicumarol routine was instituted, but through error the patient received 300 mg. of dicumarol every 4 hours for 5 doses, in addition to 50 mg. of heparin every 4 hours for the same number of doses. When the mistake was discovered anticoagulant therapy was discontinued at once and 60 mg. of synthetic vitamin K were administered intravenously. The prothrombin level remained fairly low for several days, but no hemorrhagic difficulties ensued and the patient's condition was not alarming at any time.

In 4 patients in this series of 23, dicumarol was given before operation and an adequate reduction in prothrombin level had already been attained by the time of operation. Two of these patients received, in addition, single doses of heparin during the operation. In all 4 patients dicumarol was continued for approximately 21 days.

One patient in this series received no anticoagulant treatment other than a single dose of heparin given at the time of operation.

ANALYSIS OF RESULTS

Of the 23 patients receiving anticoagulant therapy 15 recovered with no complications, in 3 thrombosis developed, and in 5 some later difficulties with bleeding occurred. It should be emphasized that in spite of the thrombosis, there was no evidence of propagation of the clot in any of the 3 patients. No difficulty with hemostasis was experienced at operation in any case in this series regardless of whether heparin was administered immediately before the anastomosis was accomplished, or whether the prothrombin time had been altered before the operation through the administration of dicumarol. Fibrin foam was frequently placed in the wound as a safeguard and this precaution appeared to give some protection against bleeding from the operative site without adding any risk of intravascular clotting.

Details of the cases in which complication followed the operative procedure are as follows: In 3 patients receiving anticoagulant therapy, thrombosis developed. In 2 of these patients, end-to-end suture had been performed for a traumatic aneurysm of the distal end of the brachial artery. In both instances the proximal end of the artery was perfectly normal, but the distal segment was somewhat scarred. Further resection of that end, in order to have available for suture a longer strip of normal artery, was impossible because of the

proximity of the bifurcation of the artery into its radial and ulnar branches. Both patients received heparin immediately after operation. The first also received dicumarol for a period of 14 days. The second was the patient mentioned previously who through error was given a large amount of dicumarol during the first 20 hours following operation and following this discovery no anticoagulants at all. The thrombosis which developed in both patients can very logically be attributed to the local arterial damage.

The third patient in whom thrombosis developed had had a defect in the brachial artery repaired by vein graft. An adequate prothrombin level had already been achieved with dicumarol at the time of operation. A single dose of heparin was given during the operative procedure and dicumarol was continued for about 14 days thereafter. While no explanation for the thrombosis in this patient is apparent, the artery was unusually small and it is not unlikely that an imperfect suture may have been the cause even though the completed anastomosis appeared to be satisfactory at the time of operation.

In 5 patients difficulty with bleeding was encountered. In 1 patient a hematoma of moderate size developed in the wound. Lateral suture of the subclavian artery had been performed and the patient was receiving dicumarol. The operative site was explored on the 10th day and a large clot evacuated. No bleeding was encountered and the wound was closed; convalescence was thereafter uneventful. A second patient, in whom a vein graft to the popliteal artery had been performed, had a small hematoma which was evacuated without difficulty. There was no further bleeding during the 6-week period in which dicumarol was administered.

A third patient developed a large hematoma after excision of a femoral arteriovenous fistula repaired by vein transplant. Two hours after the operation brisk bleeding occurred. The wound was explored and a small branch to the muscle found to be the source of the bleeding. This artery was ligated, the wound closed, and no further difficulty occurred although dicumarol was continued for several weeks.

In a fourth patient a slow, steady oozing of bright red blood from the wound was noted shortly after a femoral arteriovenous fistula had been excised and a vein graft performed. Heparin was continued intermittently in spite of the bleeding until the fourth day after operation when an adequate prothrombin level was obtained with dicumarol. By this time the blood loss had been sufficient to result in a significantly lowered erythrocyte count. The patient was given a transfusion of whole blood and 50 mg. of synthetic vitamin K. The wound was thereafter explored, but was closed promptly when only diffuse capillary bleeding was found. No further bleeding occurred.

It is noteworthy that in none of these 4 patients did thrombosis of the repaired arterial segment take place.

In a fifth patient the brachial artery remained patent after a lateral suture in the presence of gross infection. Hemorrhage, however, occurred through

the sutured defect on the 13th postoperative day. Exploration of the wound revealed that no healing of the suture line had taken place. The segment was excised and the artery ligated. The results in this patient were good. Since dicumarol had been discontinued for 10 days before the bleeding took place, it seems unlikely that this agent was implicated in the bleeding. Hemorrhage was probably caused by nonhealing consequent to infection.

Analysis of Results in Patients Not Receiving Anticoagulant Therapy

No control group, as such, existed for the patients who received anticoagulant therapy following arterial repair. Anticoagulants were reserved, as a rule, for those in whom the type of repair was such that the hazard of thrombosis was greater. Since the 11 patients in this series denied this therapy were those with the simpler types of repair, they cannot be considered proper controls. Notwithstanding, the results in these patients are considered of value for comparative purposes.

In 9 of the 11 patients not receiving anticoagulants following arterial repair, recovery was uncomplicated. In 1 patient thrombosis developed and in 1 the fistula recurred. In the former, a femoral arteriovenous fistula was resected and the rent in the artery repaired by lateral suture. The success of the operation seemed questionable when it was performed because there was obvious injury to the arterial wall in the neighborhood of the fistula and because the vessel was constricted to about one-half its normal diameter by the suture. Blood flowed freely through the segment, however, and it was decided to do nothing further. Two hours after operation it was apparent from the absence of pulsations in the popliteal, the dorsalis pedis, and the posterior tibial arteries that thrombosis had occurred. When the wound was reexplored a thrombus was found which was sharply limited to the repaired segment of the artery and was without proximal or distal propagation. The segment was excised and the artery ligated. In retrospect it would seem that in this instance the segment should have been excised originally and vein transplantation performed. The use of anticoagulants also would have been wise.

In a second patient a fistula was ligated and transfixed, but division of the vein was not performed nor a cuff of vein used to buttress the ligated fistula. This was the only instance in this series in which this technique was used. Recurrence was prompt and subsequent excision and quadruple ligation of the vessels were required.

In the remaining 9 patients not treated by anticoagulants there were no untoward results.

COMMENT

The efficacy of heparin in the prevention of thrombosis in aneurysms treated by arterial repair had been suggested by experimental and clinical evidence for some time before World War II. Later it became evident that

dicumarol was of benefit in reducing the incidence of postoperative venous thrombosis and pulmonary embolism and, on the basis of experience in other types of surgery, it seemed likely that it would be equally effective in reducing the incidence of postoperative thrombosis after arterial repair. The experience at Mayo General Hospital does not furnish complete proof of its effectiveness, however, since no true control group existed and since most patients in this series received heparin as well as dicumarol. Untreated cases recorded in the literature cannot be used for controls because so many other factors are important in evaluating the success of arterial surgery, as, for example, the type of repair, the proficiency of the surgeon, the presence or absence of infection, and the degree and extent of the local arterial injury or disease.

It is believed that dicumarol was of benefit in preventing arterial thrombosis in the present series, but that it is not a complete safeguard is suggested by the observation that adequate and prolonged anticoagulation therapy did not prevent thrombosis in all patients. The conclusion therefore seems warranted that, helpful as anticoagulants may be, their use will not be attended with success unless (1) local damage to the sutured artery is not great and (2) the surgical repair is properly executed.

It is of interest, as mentioned previously, that in none of the 3 patients in whom thrombosis occurred following anticoagulant therapy was there any evidence of extension of the clot from the repaired segment. However, in the 1 patient who did not receive anticoagulants following arterial repair and in whom thrombosis occurred, there was also no evidence of extension of the clot. An analysis of these 4 cases suggests the extreme importance of the maintenance of a good blood flow in the distal segment through adequate collateral channels and it seems reasonable to assume that anticoagulant therapy will prove of aid in the important problem of prevention of distal extension of the clot.

It would seem pertinent to this discussion to mention the results, from the standpoint of postoperative thrombosis, in the other 254 lesions treated at this center. In this group the affected artery was ligated and divided and anticoagulants were not used prophylactically. In two patients postoperative thrombosis occurred.

In the first patient a partial hemiplegia, presumably caused by distal propagation of a thrombus, developed some hours after ligation of the internal carotid artery for an intracranial carotid aneurysm. This patient recovered.

In the second patient disaster of great moment occurred. The patient had a femoral arteriovenous fistula, just distal to the point at which the profunda is given off, which necessitated excision and quadruple ligation of the vessels. Good circulation was maintained in the foot until the sixth postoperative day when there was sudden intense pain in the calf and the foot. This was followed by swelling of the leg, coldness and pallor of the foot. The patient stated that this foot was numb. On examination it was evident that extensive venous

and arterial thrombosis had occurred. In spite of poor response to spinal analgesia in respect to both color and temperature, sympathectomy was performed as a last resort. The warmth and sensation of the foot were significantly improved by this procedure, but the increase in circulation was insufficient to prevent gangrene of the sole of the foot and amputation was subsequently necessary. Anticoagulants were begun shortly after the difficulty was first noted, but no apparent therapeutic effect resulted.

Although this was the only case in the large experience at the Mayo General Hospital in which postoperative thrombosis occurred in an extremity after nonreparative surgery for aneurysm or arteriovenous fistula, it suggests the thought that the routine use of anticoagulants in the surgery of peripheral aneurysms and fistulas, whether or not reparative surgery is done, may be valuable in avoiding the uncommon but disastrous occurrence of postoperative thrombosis. Such a program would undoubtedly result in a higher instance of hematomas and oozing, but these difficulties, experience indicates, would probably not be serious.

With regard to the choice of anticoagulant agents dicumarol has apparent advantages over heparin both in cost and in ease of administration. It must not, however, be used in any institution in which it is not possible and economically feasible to provide facilities for accurate daily determinations of the blood prothrombin level. Its uncontrolled administration is fraught with great danger, and under these circumstances heparin can be employed more safely.

The experience at the vascular center of Mayo General Hospital suggests that it is more desirable to obtain an adequate prothrombin level before operation by means of dicumarol than to begin anticoagulant therapy with heparin at the time of the surgical procedure. Under this plan, there is no necessity to use heparin intravenously during the first few days after operation.⁶

CONCLUSIONS

Although the clinical applicability of anticoagulant therapy cannot be precisely defined from the Mayo General Hospital experience, it is evident that this method must be used on very strict indications and contraindications. The experience at this installation suggests that surgery of the peripheral arteries can be undertaken safely at a time when a full anticoagulant effect has already been obtained either from dicumarol or heparin. In such cases, however, it is imperative that adequate hemostasis be achieved before the wound is closed. Fibrin foam proved helpful in control of capillary bleeding, and other coagulant sponges would probably be equally useful. In spite of such precautions it must be assumed that the use of anticoagulant agents will result in

⁶ Additional postwar studies on the efficacy of these agents in the prevention of thrombosis were carried out by one of the authors of this chapter. See Klesewetter, W. B., and Shumacker, H. B., Jr.: Experimental study of comparative efficacy of heparin and dicumarol in prevention of arterial and venous thrombosis. *Surg., Gynec. & Obst.* 86: 687-702, Jun 1948. Ed.

certain increases in the incidence of hematoma and in persistent oozing from wounds, though the possible dangers of such complications are minimal if they are recognized promptly and treated properly by withdrawal of anticoagulant therapy, by surgery, if that is indicated, and by the use of reversing agents such as synthetic vitamin K.

Although no proof of the effectiveness of anticoagulants was furnished by this study, the impression was gained that this therapy renders less likely thrombosis of the repaired segment of an artery.

CHAPTER XI

Arterial Aneurysms and Arteriovenous Fistulas Sympathectomy as an Adjunct Measure in Operative Treatment

Harris B. Shumacker, Jr., M. D.

Part I. Preoperative Sympathectomy and Sympathectomy Coincidental With Vascular Surgery

Interruption of the sympathetic pathways as a preliminary to surgical extirpation of an aneurysm was introduced in 1934 by Gage¹ and in 1935 by Bird.² They were unaware of each other's activities. Gage used alcohol injections and Bird ganglionectomy.

Bird, although he was impressed with the apparent improvement of the collateral circulation achieved by this method, presented his contribution with definite reservations because he was hopeful that the pavex boot, which had recently been introduced, might make unnecessary any other effort to foster development of the collateral circulation. Gage, on the other hand, was convinced that sympathetic interruption would continue to occupy a prominent place in the surgical management of aneurysms. He and Ochsner³ subsequently reported additional successful experiences with this procedure.

After 1934 when Gage's original contribution appeared, a number of other observers reported the use of sympathectomy as an adjunct measure in the management of aneurysms and recommended that it be performed either before the vascular operation or as part of the vascular procedure.⁴

¹ Gage, I. M.: Mycotic aneurysm of common iliac artery; sympathetic ganglion block as aid in development of collateral circulation in arterial aneurysm of peripheral arteries; report of a case. *Am. J. Surg.* 24: 667-710, Jun 1934.

² Bird, C. E.: Sympathectomy as a preliminary to the obliteration of popliteal aneurysms; with a suggestion as to sympathetic block in cases of ligature, suture, or thrombosis of large arteries. *Surg., Gynec. & Obst.* 60: 926-929, May 1935.

³ (1) Gage, M., and Ochsner, A.: The prevention of ischemic gangrene following surgical operations upon the major peripheral arteries by chemical section of the cervicodorsal and lumbar sympathetics. *Ann. Surg.* 112: 938-959, Nov 1940.

(2) Gage, M.: The development of the collateral circulation in peripheral arterial aneurysms by sympathetic block. *Surgery* 7: 792-795, May 1940.

⁴ (1) Veal, J. R.: The value of sympathetic interruption following the surgical repair of peripheral aneurysms. *M. Ann. District of Columbia* 9: 227-230, 1940.

(2) Richards, R. L., and Learmonth, J. R.: Lumbar sympathectomy in treatment of popliteal aneurysm. *Lancet* 1: 383-384, 28 Mar 42.

(3) Pemberton, J. deJ., and Black, B. M.: Surgical treatment of acquired aneurysm and arteriovenous fistula of peripheral vessels. *Surg., Gynec. & Obst.* 77: 462-470, Nov 1943.

(4) Kirtley, J. A., Jr.: Arterial injuries in a theater of operations. *Ann. Surg.* 122: 223-234, Aug 1945.

(5) Freeman, N. E.: Secondary hemorrhage arising from gunshot wounds of the peripheral blood vessels. *Ann. Surg.* 122: 631-640, Oct 1945.

(6) Harbison, S. P.: Experiences with aneurysms in an overseas general hospital. *Surg., Gynec. & Obst.* 81: 123-137, Aug 1945.

(7) Albright, H. L., and Van Hale, L. A.: Traumatic aneurysms; a study of 43 cases in an overseas general hospital. *Surgery* 20: 452-477, Oct 1946.

(8) Warren, R.: War wounds of arteries. *Arch. Surg.* 53: 86-99, Jul 1946.

All the reported cases were successful; the circulation apparently proved adequate after operations which necessitated ligation of the affected artery. The universally successful results reported in these contributions created the impression, perhaps contrary to the intent of the authors, that sympathectomy provides an almost impregnable defense against ischemic disaster in vascular lesions treated by ligation of main arteries.

In the vascular centers during World War II the general usefulness of sympathectomy was confirmed, but at the same time certain limitations were revealed. At the vascular center of Ashford General Hospital sympathectomy was used only occasionally in the management of aneurysms; at the vascular centers of both DeWitt and Mayo the experience with sympathectomy was extensive. At the last-named hospital a study was made of sympathectomy as an adjuvant in the operative treatment of vascular lesions. The purpose of this study was twofold: to determine the merits and limitations of sympathectomy, and to formulate a logical plan for its use.

There is ample experimental and clinical evidence to support the view that sympathectomy is of real help in maintaining an efficient circulation in various conditions in which the continuity of the blood flow through important arterial trunks has been interrupted. There are two concepts regarding the mechanism by which this efficient circulation is achieved:

1. Sympathectomy ensures the fullest use of the existing collateral circulation because it eliminates vasoconstrictor impulses and thus contributes to the maintenance of near-maximum circulation. This concept is well established.

2. Sympathectomy brings about more rapid growth of new collateral channels because it reduces peripheral resistance to the blood flow (or perhaps the new channels are brought about by some other mechanism). This explanation is still hypothetical and will require considerable investigative support before it can be considered factual.

The point of view might readily be defended that sympathectomy should be performed upon every patient with an aneurysm or fistula if cure might entail ligation of an important arterial stem. Clinical experience during World War II demonstrated, however, that large numbers of aneurysms and fistulas can be extirpated without serious ischemic difficulties provided (1) the data secured by careful testing of the collateral circulation are used as a guide in the selection of the proper time for operation, and (2) the operation is so carried out that no collateral blood vessels are needlessly sacrificed. Some investigators hold that sympathectomy should be used almost uniformly in the surgical management of aneurysms and fistulas, others take the position that the procedure should rarely, if ever, be employed. At the vascular center of Mayo General Hospital a practice between these two extremes was followed: Sympathectomy was utilized whenever it might reasonably be expected to result in benefit to the patient. Undoubtedly it was carried out more often

than was actually necessary, as, for example, to prevent gangrene. In spite of this possibly excessive use, it may be said that if clear-cut benefit did not follow in every instance in which it was employed, at least no harmful results were noted.

CLINICAL MATERIAL AND METHODS

This analysis is based upon 75 sympathectomies (Table 35) performed on 288 patients either before or in the course of operations for aneurysm or arteriovenous fistula at the vascular center of Mayo General Hospital during World War II.⁵ In an additional 13 patients 2 sympathectomies were carried out in anticipation of operation, but no operative treatment proved necessary because in all 13 spontaneous cure of the lesion by thrombosis occurred. One other sympathectomy might properly be added to this group. It was performed on a patient in whom physical findings pointed to a diagnosis of aneurysm, but surgical intervention established the fact that the signs were caused by costoclavicular compression of the subclavian artery (see Chapter IV).

TABLE 35. SYMPATHECTOMY PERFORMED BEFORE OR AT THE TIME OF OPERATION FOR ANEURYSM OR ARTERIOVENOUS FISTULA

Location of lesion	Arterial aneurysms			Arteriovenous fistulas		
	Number of patients operated upon	Number of patients treated by sympathectomy	Percent treated by sympathectomy	Number of patients operated upon	Number of patients treated by sympathectomy	Percent treated by sympathectomy
Innominate.....	1	1	100.0			0
Subclavian.....	5	1	20.0	6	2	33.3
Axillary.....	13	6	46.2	12	4	33.3
Brachial.....	22	4	18.2	11	2	18.2
Femoral.....	6	4	66.7	50	16	32.0
Popliteal.....	14	11	78.6	41	14	34.1
Other.....	21	1	4.8	86	7	10.5
Total.....	82	28	34.1	206	47	22.8

There were no deaths and no serious complications in these 302 patients.

Indications. In the 77 patients upon whom sympathectomy was performed there were 7 chief indications for interruption of the sympathetic pathways (Tables 36-42):

1. Evidence of poor collateral circulation in patients with lesions of sufficiently long duration to have produced, under ordinary circumstances, a fairly efficient collateral circulation.

⁵ Two hundred eighty-eight aneurysms and fistulas were treated surgically at this hospital, 63 lesions were treated in which surgery had been performed prior to transfer to this hospital, and 13 lesions were observed in which spontaneous cure occurred. These 364 lesions occurred in 351 patients (9 patients presenting a total of 22 lesions). Unfortunately in the distribution of patients and lesions, the differentiation became obscured and in this discussion the designation "patient" will be used for "patient/lesion" since so few patients presented multiple lesions.

2. The presence of an inadequate collateral circulation in association with peripheral nerve injuries requiring surgical exploration. The management of this type of case was a problem. Early surgical treatment of peripheral nerve injuries was desirable because it resulted in better return of function than the late treatment of such lesions. On the other hand, it was hazardous to explore the nerve before the aneurysm or fistula had been treated. Every effort was made therefore to increase the efficiency of the collateral circulation as promptly as possible, particularly because it was usually feasible to carry out both the vascular operation and the neurosurgical procedure at the same time.

3. The impossibility of testing the collateral circulation in certain patients in whom an important arterial trunk appeared to be involved. This indication was not often a valid reason for sympathectomy, but in an occasional patient the affected artery could not be compressed at the site of the fistula or aneurysm and accurate preoperative testing of the collateral circulation was impossible.

4. The association of the aneurysm or fistula with an ischemic lesion.

5. Intense local vasospasm in the affected limb, or a rather severe generalized vasospastic disorder.

6. The loss of one or more major arteries by previous injury or operation in a limb in which the cure of an aneurysm or fistula was likely to necessitate ligation of other important arterial channels.

7. Causalgia in the affected limb which could be relieved temporarily, but not cured, by sympathetic blocks.

Technique. At this center interruption of vasoconstrictor impulses was achieved by surgical resection rather than by paravertebral alcohol injection. Operative sympathectomy was preferred for two reasons (1) surgical interruption has a more lasting effect, and (2) neuritic pains sometimes constitute distressing sequelae of alcohol injection. Twenty-four of the 77 sympathectomies involved dorsal, and 53 lumbar, operations. Lumbar sympathetic gangliectomy was performed through an anterior extraperitoneal muscle-splitting incision. These operations were carried out with the aid of spinal analgesia. Dorsal sympathectomy was accomplished by the preganglionic operation devised by Smithwick.⁶ It was carried out with the patient under intratracheal gas-oxygen-ether anesthesia.

Anatomic Distribution of Operations. The majority of the 77 sympathectomies were in patients with lesions of the larger peripheral arterial stems. If we exclude the 2 cases in which spontaneous cure without vascular surgery followed sympathectomy (Cases 27 and 47), it will be seen that the 75 sympathectomies represent 26 percent of the 288 patients with aneurysms or arteriovenous fistulas treated at this center by surgical methods. (Table 35.) One hundred thirty-six of these patients had lesions of the femoral, popliteal, or axillary arteries. It was upon this group that most of the sympathectomies were

⁶ Smithwick, R. H.: The rationale and technic of sympathectomy for the relief of vascular spasm of the extremities. *New England J. Med.* 222: 699-703, Apr 1940.

performed (55 sympathectomies). In the 44 patients with lesions of the subclavian and brachial arteries, sympathectomy was performed only 9 times. In the remaining 108 patients with lesions of arteries not included in the foregoing breakdown, only 11 sympathectomies were performed. Moreover, as will be pointed out shortly, sympathectomy was performed upon a number of patients in the miscellaneous group because preoperative study had erroneously indicated that an important artery near the affected vessel was involved in the lesion.

Proportionately, sympathectomy was performed more often upon patients with arterial aneurysms than upon those with arteriovenous fistulas (Table 35). The discrepancy is more apparent if only those patients with lesions of axillary, femoral, and popliteal lesions are considered, since it was upon these patients that sympathectomy was most frequently done. The relative percentages for axillary, femoral, and popliteal aneurysms were, respectively, 46.2, 66.7, and 78.6, in contrast to percentages for arteriovenous fistulas of 33.3, 32.0, and 34.1. Although these differences are primarily a reflection of the tendency to poorer collateral circulation in instances of arterial aneurysms, they can also be explained by the fact that associated nerve injuries requiring operative treatment were twice as common in arterial aneurysms as in arteriovenous fistulas. The difference cannot be explained by a higher incidence of involvement of major arterial stems in arterial aneurysm than in arteriovenous fistula; 46.3 percent of the arterial aneurysms operated on in this series involved the subclavian, axillary, femoral, and popliteal arteries, against 52.9 percent involvement of these arteries in arteriovenous fistulas. This is not a significant difference.

INDICATIONS FOR PREOPERATIVE SYMPATHECTOMY

The results of sympathectomy (Tables 36-42) can best be analyzed if they are considered in relation to the chief indications for the procedure. It should, of course, be borne in mind that in a number of patients sympathectomy was decided upon not for a single reason but for a combination of reasons.

In all of the patients included in this analysis the status of the collateral circulation was investigated by the repeated use of a number of tests and observations (see Chapter II). Chief reliance, however, was placed upon the reactive hyperemia test devised by Matas.

Poor Collateral Circulation

Poor collateral circulation was the chief indication, or a major indication, for sympathectomy in 38 of the 77 patients upon whom it was performed (Tables 36 and 37). There were, however, other indications in this group. In 16 patients, for instance, associated peripheral nerve lesions required operative treatment. In a number of patients severe pain or pronounced vasospasm was present and in 1 patient superficial gangrene was the indication.

In all 38 patients in this group, intermittent proximal occlusion of the involved artery had been practiced without apparent improvement in the collateral circulation, though in only a few instances had this method been given a prolonged trial.

TABLE 36. SYMPATHECTOMY PERFORMED BEFORE OPERATION FOR ANEURYSM OR FISTULA.
[Indication—Poor Collateral Circulation; Patients in Whom Collateral Circulation Became Satisfactory Following Sympathectomy]¹

Case No.	Location of lesion	Interval between injury and sympathectomy	Interval between sympathectomy and operation	Type of operation	Comment	Results
Cases of Arterial Aneurysms						
1	Axillary	Months 3.0	Weeks 2.0	E	Also had brachial plexus injury requiring neurolysis.	Good; has some cold sensitivity.
2	Brachial	5.5	5.0	E	Also plexus injury requiring neurolysis.	Excellent.
3	Brachial	5.0	2.0	E	Also median and ulnar palsy; median neurolysis, ulnar neurorrhaphy.	Excellent.
4	Brachial	3.0	10.0	A-E	Also plexus injury requiring neurolysis; collateral circulation did not become satisfactory for 2 mo.	Excellent.
5	Femoral	5.5	1.0	E		Excellent.
6	Popliteal	2.0	3.0	A	Very large, subcutaneous rupture, severe pain, pain less after sympathectomy.	Excellent.
7	Popliteal	5.0	3.0	A		Excellent.
8	Popliteal	5.5	5.0	A		Excellent.
Cases of Arteriovenous Fistulas						
9	Subclavian	5.0	3.0	E	Also ulnar palsy, requiring neurolysis.	Excellent.
10	Axillary	3.0	2.5	E	Also plexus injury, neurolysis, radial neurorrhaphy, hand cold, blue before sympathectomy; circulation strikingly improved.	Excellent.
11	Axillary	5.0	3.5	E	Also plexus injury, requiring neurolysis.	Excellent.
12	Axillary	6.5	2.0	E		Excellent.
13	Axillary	6.5	3.0	II	Also plexus injury, ulnar and radial neurorrhaphy necessary.	Excellent.
14	Brachial	3.0	7.5	E	Also ulnar and median palsy requiring neurolysis, collateral circulation very poor before, good after sympathectomy.	Excellent.
15	Common Femoral.	5.5	1.0	E		Excellent.
16	Femoral	3.0	2.0	E		Excellent.
17	Femoral	2.5	21.0	E	Also peroneal palsy, F. C. C. femur and pain; collateral circulation adequate shortly after sympathectomy; burning pain disappeared.	Excellent.
18	Femoral	3.0	5.0	E-R	Collateral circulation improved progressively over period of several weeks after sympathectomy.	Excellent; successful vein graft to arterial defect.

See footnote at end of table.

TABLE 36. SYMPATHECTOMY PERFORMED BEFORE OPERATION FOR ANEURYSM OR FISTULA—Continued

[Indication—Poor Collateral Circulation; Patients in Whom Collateral Circulation Became Satisfactory Following Sympathectomy] ¹—Continued

Case No.	Location of lesion	Interval between injury and sympathectomy	Interval between sympathectomy and operation	Type of operation	Comment	Results
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Cases of Arteriovenous Fistulas

		<i>Months</i>	<i>Weeks</i>			
19	Popliteal.....	2.5	2.0	E	Also peroneal palsy.....	Excellent.
20	Popliteal.....	3.5	1.5	E	Also pronounced vasospasm.....	Excellent.
21	Popliteal.....	3.5	2.0	E	Also peroneal palsy requiring suture..	Excellent.
22	Popliteal.....	4.0	3.0	E	Collateral circulation thought adequate after sympathectomy.	Poor, gangrene of distal third of the foot.
23	Popliteal.....	10.0	3.0	E	Also peroneal palsy.....	Excellent.
24	Popliteal.....	9.0	4.0	E-R	.....	Excellent; continuity of artery maintained; ligation of fistula.

¹ Abbreviations used in this table:
E, Excision.
A-E, Excision with restoration or maintenance of continuity of affected artery.
A, Aneurysmorrhaphy or aneurysmotomy with intrasaccular ligation or transfixing of the artery.
E-R, Aneurysmorrhaphy or similar procedure followed by excision of the sac.
F. C. C., Fracture compound comminuted.

TABLE 37. SYMPATHECTOMY PERFORMED BEFORE OPERATION FOR ANEURYSM OR FISTULA

[Indication—Poor Collateral Circulation; Patients in Whom Collateral Circulation Did Not Become Satisfactory Following Sympathectomy] ¹

Case No.	Location of lesion	Interval between injury and sympathectomy	Interval between sympathectomy and operation	Type of operation	Comment	Results
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Cases of Arterial Aneurysms

		<i>Months</i>	<i>Weeks</i>			
25	Axillary.....	3.5	9.0	A-E-R	Also plexus injury requiring neurolysis.	Excellent; successful end-to-end suture.
26	Brachial.....	4.0	6.5	A-E	Also plexus injury requiring neurolysis and radial neurorrhaphy.	Excellent.
27	Femoral.....	2.0	.....	None	Thrombosis occurred after sympathectomy with gradual obliteration of sac.	Excellent.
28	Popliteal.....	2.0	8.5	A	.....	Excellent.
29	Popliteal.....	4.0	15.0	A	.....	Excellent.
30	Popliteal.....	Unknown	17.0	E-R	Aneurysm due to medionecrosis; circulation in foot poor before, good after sympathectomy.	Excellent; successful vein graft.

See footnote at end of table.

TABLE 37. SYMPATHECTOMY PERFORMED BEFORE OPERATION FOR ANEURYSM OR FISTULA—Continued

[Indication—Poor Collateral Circulation; Patients in Whom Collateral Circulation Did Not Become Satisfactory Following Sympathectomy] ¹—Continued

Case No.	Location of lesion	Interval between injury and sympathectomy	Interval between sympathectomy and operation	Type of operation	Comment	Results
Cases of Arteriovenous Fistulas						
31	Femoral.....	Months 3.5	Weeks 31.0	E-R	Collateral circulation improved after sympathectomy but never satisfactory.	Excellent; continuity of artery maintained, fistula ligated.
32	Femoral.....	7.0	5.0	E-R	Collateral circulation improved markedly after sympathectomy; became questionably adequate.	Excellent; continuity of artery maintained, fistula ligated.
33	Femoral.....	5.0	9.0	E-R	Collateral circulation improved slightly but never became adequate.	Excellent; continuity of artery maintained, fistula ligated.
34	Popliteal.....	3.5	10.0	E-R	Collateral circulation improved markedly after sympathectomy; never entirely satisfactory.	Excellent; continuity of artery maintained, fistula ligated.
35	Popliteal.....	6.5	10.0	E-R	Also peroneal palsy requiring suture; collateral circulation improved but never became satisfactory.	Excellent; continuity of artery maintained, fistula ligated.
36	Popliteal.....	5.0	5.0	E-R	Collateral circulation improved but never became completely satisfactory.	Excellent; continuity of artery maintained, fistula ligated.
37	Popliteal.....	11.0	3.5	E	Collateral circulation improved but never became satisfactory.	Excellent.
38	Popliteal.....	5.0	13.0	E-R	Collateral circulation improved slightly but never became satisfactory.	Excellent; continuity of artery maintained, fistula ligated.

¹ Abbreviations used in this table:
A-E-R, Aneurysmorrhaphy or similar procedure followed by excision of the sac and by restoration of continuity of the artery.
A-E, Aneurysmorrhaphy or similar procedure followed by excision of the sac.
A, Aneurysmorrhaphy or aneurysmotomy with intrasaccular ligation or transfixing of the artery.
E-R, Excision with restoration or maintenance of continuity of affected artery.
E, Excision.

Of this group of 38 patients, sympathectomy was carried out when the lesion had been present 5 months or more in 18, 3 months but less than 5 months in 14, and less than 3 months in 5. In 1 patient (Case 30) the aneurysm was caused by medionecrosis and it was not possible to determine the time interval. In the 5 patients upon whom sympathectomy was performed even though the lesion had been present for less than 3 months, circumstances existed which made it seem advisable to undertake it without further delay.

Two of these 5 patients (Cases 6 and 17) had severe pain. In 1 of them a popliteal aneurysm had ruptured subcutaneously and it was obvious that a further increase in its size might necessitate operation at any moment. The other had severe causalgia associated with a femoral arteriovenous fistula, a

saccular aneurysm and peroneal paralysis, in addition to a compound comminuted fracture of the femur, intense vasospasm of the foot, an ulcer of the heel, and superficial gangrene of the toes. His pain had been so severe that narcotics had been used to the point where there was real danger of addiction. In both of these patients pain was diminished or relieved shortly after sympathectomy had been performed, and tests thereafter showed the collateral circulation to be satisfactory.

A third patient (Case 19), with a popliteal aneurysm of 2½ months duration, had extremely poor collateral circulation and complete peroneal paralysis. The collateral circulation became adequate soon after sympathectomy and early treatment of the aneurysm and nerve lesion was possible. The fourth patient (Case 27) had a femoral aneurysm and the fifth (Case 28) a popliteal aneurysm. Both of these lesions had been present for 2 months and in both patients the collateral circulation was extremely poor. Although the tests did not show the collateral circulation to be entirely satisfactory in either patient after sympathectomy, they did show some improvement. Spontaneous cure occurred in 1 patient, and in the other success followed operative treatment 2 months after sympathectomy.

Twenty-four of the 38 patients upon whom sympathectomy was performed because of inadequate circulation showed evidence of satisfactory collateral circulation subsequent to the operation, and in the majority, tests showed it to be adequate very shortly after sympathectomy. There was no great difference in this respect between those patients with arterial aneurysms and those with arteriovenous fistulas. In 8 of 14 patients with aneurysms and in 16 of 24 with fistulas, evidence of good collateral circulation became apparent after sympathectomy according to the reactive hyperemia test and other tests used for this purpose.

In these 24 patients (see Table 36) the vascular operation was not always performed as soon as tests showed the collateral circulation to be adequate; some patients were permitted to return home on sick leave between operations. In some instances the second operation was deferred because of an illness unrelated to the vascular lesion, e. g., malaria or gastroenteritis. In most instances, however, operation on the vascular lesion was performed shortly after sympathectomy. In 9 of the 24 patients it was done within 2 weeks, in 16 within 3 weeks or less, and in 18 within 4 weeks or less (the figures are cumulative). In only 6 instances was operation delayed 5 weeks or longer. In 1 of these patients (Case 17) tests showed the collateral circulation to be adequate shortly after sympathectomy, but operation had to be deferred because of a compound fracture of the femur and infected ulcers of the foot. In the other 4 patients tests showed that the collateral circulation improved slowly and steadily after sympathectomy.

In all but 2 of the patients listed in Table 36, cure of the aneurysm or fistula required ligation of the affected artery. In the 2 exceptions (Cases

18 and 24) continuity of the artery was preserved or reestablished by ligation of the fistula or by bridging the arterial defect with a vein graft.

In the statement of results the term excellent in this and in other tables should be understood to mean that the limb was of normal warmth and color under ordinary environmental conditions, that there was no significant or disturbing sensitivity to cold, and that there was satisfactory evidence of the return of nerve function. If the patient was not followed long enough for restoration of sensation and motor power to become evident, such evidence as progression distally of the point at which Tinel's sign might be elicited was interpreted to mean satisfactory improvement as compared with that recorded by patients with nerve injury but in whom no vascular disorder existed. Naturally, there was no regeneration of those nerves in which apparently irreparable damage had occurred and on which no reparative procedure could be carried out. The term excellent should not be understood to imply that no fatigue was present on exercise. This finding was invariably noted in patients who had had arteries ligated, especially the femoral or the popliteal.

One patient (Case 1) had some cold sensitivity following an operation in which it was necessary to ligate the axillary artery, and in another (Case 22) gangrene of the distal third of the foot occurred after operation.

Case 22. This patient, a 35-year-old soldier, had a popliteal arteriovenous fistula. No flush was present during the reactive hyperemia test. Sympathectomy was performed 4 months after the injury and immediately afterward tests showed definite improvement in the collateral circulation. The flush appeared promptly after deflation of the constricting cuff and steadily improved becoming full and complete in 2 minutes; there was no further improvement upon release of pressure from the popliteal artery. Similar results were obtained on several occasions.

The fistula was explored 3 weeks after sympathectomy. A large communication was found between the popliteal artery and vein and there was present in addition a small sacular aneurysm of the popliteal artery from which emerged a large geniculate branch. This branch had to be ligated in the course of the excision. It seemed probable that during the preoperative tests the fistula had been occluded without interruption of the blood supply through this branch and that the information concerning the state of the collateral circulation had therefore been misleading. At the conclusion of the operation both the color and the warmth of the foot were poor and within a few days gangrene was apparent. Amputation of the distal third of the foot was necessary.⁷

Comment. This case has been described in some detail because it illustrates a number of points: (1) that sympathectomy offers no guarantee against ischemic disaster; (2) that tests for collateral circulation may sometimes be fallible, and (3) that it is essential to take every possible precaution in vascular surgery. In this connection it should be mentioned that one essential precaution was omitted in the case described above. The drapes used at operation were applied in such a way that the foot was not in view during the procedure; a

⁷ The author of this chapter, in a total military and civilian experience covering 56 femoral and 55 popliteal aneurysms and arteriovenous fistulas treated by surgical means, observed only 1 other case in which gangrene occurred under these circumstances. In this case thrombosis developed on the sixth postoperative day, in a limb in which the circulation had previously been excellent.

precaution which should never be omitted in any instance in which doubt exists as to the adequacy of the collateral circulation. It was unfortunately omitted in this case because of the false sense of security which prevailed: Up to this time in the hospital experience, ischemic difficulty had never occurred in a limb following sympathectomy, and there had never been an episode to suggest that the reactive hyperemia test might give misleading information.

In 14 patients (Table 37) the collateral circulation was adjudged inadequate following sympathectomy. In all, however, there was some improvement over that shown by preoperative tests. In a few the improvement was quite noticeable but in none did the collateral circulation become adequate according to criteria established. It will be noted that in this group of patients a longer interval elapsed between sympathectomy and operation than in the group in which sympathectomy produced better results. In only 1 of the 14 patients (Case 37) was the interval less than 5 weeks, and in 9 patients, almost two-thirds of the total number, it was 2 months or longer. In 1 patient in this group (Case 27) a satisfactory spontaneous cure occurred as the result of thrombosis. In 9 patients continuity of the affected artery was maintained or restored by ligation of the fistula, by end-to-end suture, or by vein transplant. In only 4 patients was it necessary to ligate the involved artery.

In all 14 patients (Table 37) an excellent end result was obtained. The limbs were of good color and warmth, there was no sensitivity to cold, and in those patients with peripheral nerve paralysis, return of nerve function progressed satisfactorily. In those in whom the continuity of the affected artery was maintained or restored there was, in addition, no fatigue on exercise in any instance in which it had not been present before operation.

In all of the 13 patients upon whom operation was performed (in 1 patient [Case 27] spontaneous cure occurred by thrombosis and operation was unnecessary) color and warmth of the affected foot or hand were observed during operation over a prolonged period of precise occlusion of the involved artery with a rubber-shod clamp. In every patient but 1 the collateral circulation was observed to be adequate, though repeated preoperative tests had led to a different conclusion. The excellent postoperative results in the 4 patients in whom the involved artery was ligated proved that the collateral circulation was efficient. In some of the other patients anatomic conditions were found at operation which explained the reason for the misleading results of the tests carried out before operation. In some instances large collateral vessels were present which would necessarily have been occluded during digital compression, but which could be preserved at operation.

That the collateral circulation was apparently satisfactory in all but 2 of the 14 patients in this group (Cases 27 and 31) does not necessarily indicate that it was made so by sympathectomy. All that can be said is that the same tests for the collateral circulation made before and after sympathectomy showed some improvement in all instances following sympathectomy and notable improvement in a few instances but in no instance did they show the

collateral circulation to be entirely adequate according to established criteria.

Four types of response to sympathectomy were evident (Tables 36 and 37). (1) In some instances tests showed the collateral circulation to be adequate immediately after, or shortly after, sympathectomy. (2) In some instances the tests showed significant improvement soon after sympathectomy, and this was followed by slow, steady improvement until the collateral circulation became completely satisfactory some weeks later. (3) In some instances the tests showed some improvement, but never enough improvement so that the collateral circulation could be adjudged adequate before the vascular operation, though more precise tests performed with the lesion exposed at operation demonstrated that the collateral circulation actually was satisfactory. (4) In one instance tests showed the collateral circulation to be inadequate and according to all tests, including those made at operation, it remained so.

It may be profitable to illustrate these four types of response with brief illustrative case reports:

Case 5. A 32-year-old soldier who had been injured by shell fragments 15 May 1944 was admitted to Mayo General Hospital 1 September 1944 with a large aneurysm in the region of the right femoral artery. There was no essential difference in the color or temperature of the two feet. The reactive hyperemia test, carried out on several occasions between the date of admittance and the latter part of October, revealed no flush in the foot over a period of 3 minutes compression of the femoral artery although a brilliant flush appeared as soon as compression was released. Lumbar sympathectomy was performed 31 October. When the reactive hyperemia test was carried out on the third postoperative day, the flush was almost instantaneous, reaching the toes in 5 seconds and becoming complete and full in 60 seconds. There was no further improvement upon release of pressure from the femoral artery. Excision of the femoral aneurysm 6 November, with concomitant ligation of the femoral vein, produced an excellent result. There was good warmth and color in the foot at all times.

Case 18. A 26-year-old officer who had sustained an injury from a shell fragment 16 April 1945 was admitted to Mayo General Hospital 29 May with a midfemoral arteriovenous fistula. There was no flush of the foot during the reactive hyperemia test. Sympathectomy was performed 14 July. When the test was carried out again a week later, a flush appeared in some of the toes in 15 seconds and became complete and of good quality in 2 minutes. A much more brilliant flush, however, appeared when pressure was released from the femoral artery. By 17 August the reactive hyperemia test showed an excellent flush which began at the toes in 10 seconds and was complete and full in 80 seconds. There was no improvement upon release of pressure from the femoral artery. The fistula and the involved area of artery and vein were excised 20 August; a vein graft was utilized to bridge the arterial defect. The graft was successful and the patient had excellent circulation in the limb.

Case 29. A 20-year-old soldier injured 10 December 1944 was admitted to Mayo General Hospital 7 March 1945 with a fairly large popliteal aneurysm. After admittance and for the next few weeks, the flush during the reactive hyperemia test was poor and incomplete. Sympathectomy was performed 19 April. Thereafter the results of tests showed steady improvement. On 3 May a flush reached the toes in 30 seconds, improved slowly during the 2-minute period of observation, and became strikingly better upon release of pressure from the popliteal artery. By 30 July the flush reached the toes in 10 seconds. Though it improved considerably during the 2-minute period of observation, it improved still more upon release of pressure from the popliteal artery. When the aneurysm was

explored 3 August and the popliteal artery occluded with a rubber-shod clamp just proximal to the lesion, the foot was warm and of good color. The sac was opened and the artery transfixed above and below the defect. After operation the foot was always warm and of good color.

Case 31. A 27-year-old soldier, injured 26 February 1945, was admitted to the Mayo General Hospital 4 May with signs indicative of a femoral arteriovenous fistula. After admittance and for several weeks thereafter, no flush occurred during the reactive hyperemia test. Sympathectomy was performed 5 June. It was followed by only slight improvement; the flush was of poor quality and incomplete. There was no noticeable change during the following weeks. In the belief that some local factor might be responsible for the poor results of the reactive hyperemia test and that the collateral circulation might actually be adequate, as it had proved to be in other cases, the lesion was cautiously explored 25 August. When a rubber-shod clamp was placed upon the artery above and below the fistula, the foot promptly became extremely pale and cool and did not change its appearance as long as the clamps were left in place. The wound was therefore closed without an attempt to extirpate the fistula. The limb was tested repeatedly during the next few months and finally, 11 January 1946, the vessels were again explored. As at the previous operation, precise occlusion of the artery produced persistent pallor and coldness in the foot. The fistula was carefully dissected out and it became evident that it could be transfixed and reinforced by a segment of the divided vein thereby preserving the continuity of the artery. This was done and the results were excellent.

Collateral Circulation not Determinable

Sympathectomy was performed in 10 patients (Table 38) because it was impossible to compress the involved artery at the site of the aneurysm or fistula to test the status of the collateral circulation. In 3 patients the artery could

TABLE 38. SYMPATHECTOMY PERFORMED BEFORE OPERATION FOR ANEURYSM OR FISTULA
[Indication—Impossibility of Testing Collateral Circulation] ¹

Case No.	Location of lesion	Interval between injury and sympathectomy	Interval between sympathectomy and operation	Type of operation	Comment	Results
<i>Cases of Arterial Aneurysms</i>						
39	Innominate....	9.0	8.0	Triple ligation.	At previous exploration hand became completely pallid with innominate occlusion; partial proximal ligation had failed as judged by oscillometric readings, etc.	Excellent.
40	Subclavian.....	4.5	2.0	A-E	Also plexus injury requiring neurolysis.....	Excellent.
41	Axillary.....	3.5	7.0	A-E	Also plexus injury requiring neurolysis; also cold sensitivity.	Good; cold sensitivity.
42	Axillary.....	3.0	2.0	A-E	Also plexus injury requiring neurolysis.....	Excellent.
43	Femoral.....	1.5	2.5	A	Huge aneurysm, edema, coldness of foot, pain; circulation improved and pain relieved after sympathectomy.	Excellent.
44	Popliteal.....	2.0	1.0	A	Huge infected aneurysm, loss anterior tibial group muscles, large ulcer; aneurysm ruptured subcutaneously 5 days after sympathectomy forcing operation.	Excellent.

See footnote at end of table.

TABLE 38. SYMPATHECTOMY PERFORMED BEFORE OPERATION FOR ANEURYSM OR FISTULA—Continued

[Indication—Impossibility of Testing Collateral Circulation.] ¹ —Continued						
Case No.	Location of lesion	Interval between injury and sympathectomy	Interval between sympathectomy and operation	Type of operation	Comment	Results
<i>Cases of Arteriovenous Fistulas</i>						
45	Aorta-innominate-subclavian.	5.5	10.0	Exploration.	Thought before exploration to involve innominate vessels.	
46	Subclavian----	8.5	2.0	E	An intramediastinal fistula-----	Excellent.
47	Subclavian----	4.5	2.0	Exploration.	Continuous bruit and thrill disappeared after sympathectomy; slight systolic bruit remained.	Excellent; thrombosis of fistula.
48	Brachial-----	2.0	1.0	E	Huge A-V saccular aneurysm, pain and swelling prohibited testing collateral; severe plexus injury requiring neurolysis and suture, circulation of hand impaired, cold sensitivity; rupture 5 days after sympathectomy forced operation.	Good; slight cold sensitivity.

¹ Abbreviations used in this table:
A-E, Aneurysmorrhaphy or similar procedure followed by excision of the sac.
A, Aneurysmorrhaphy or aneurysmotomy with intrasaccular ligation or transfixing of the artery.
E, Excision.

not be compressed near the affected portion because the aneurysm was extremely large and the attempted maneuver was accompanied by intolerable pain. In 4 more, compression of the artery was impossible because the lesion was located in the mediastinum. In the final 3, all with axillary or subclavian lesions, the overlying clavicle and heavy musculature made it impossible to occlude the lesion near the site of the defect. Since, with a single exception (Case 39), there was no way of determining what the results might have been had sympathectomy not been performed, it was difficult to evaluate the effect of the procedure. Certain data, however, suggest that it was beneficial. Thus in the exceptional case just mentioned (Case 39), the patient had a lesion within the mediastinum. During an exploratory operation, complete pallor of the hand occurred during temporary occlusion of the innominate artery proximal to the aneurysm. A partial proximal ligation was done, but since the resulting reduction in pulsation in the extremity was so transient (confirmed by oscillometric readings) it was obvious that the procedure had failed. Sympathectomy was performed, followed by complete proximal and distal ligation. Results were excellent. The aneurysm was cured and there was excellent circulation in the hand.

Again, in two patients (Cases 41 and 48) some sensitivity to cold was present after operation. Since it is well established that this condition is

either improved or relieved by sympathectomy in instances involving ligation of the artery, there is every reason to believe that it would have been even more marked in these patients had sympathectomy not been performed.

Two patients (Cases 43 and 48) who had had severe pain before sympathectomy were more comfortable after the operation.

Four patients (Cases 40, 41, 42, and 48) who had sustained extensive damage to the brachial plexus experienced some return of nerve function following sympathectomy. In light of the state of the nerves at the time of exploration, any return of function must be considered remarkable.

In one patient (Case 47) signs of a mediastinal subclavian fistula disappeared immediately after sympathectomy as the result of thrombosis. The possible role of sympathetic denervation in bringing about a cure by means of thrombosis will be discussed later.

Obviously the sympathectomy performed upon one patient was needless (Case 45), for the vascular lesion was afterwards found to be inoperable.

Vasospasm

The only sure way to prevent vasoconstriction from jeopardizing the circulation after operation is to interrupt the sympathetic innervation. Since in operative cure requiring ligation of a main artery, maintenance of adequate circulation in a limb depends upon full utilization of existing collateral channels, persistent vasospasm should not be permitted to compromise circulation through these channels.

Sympathectomy was performed upon 6 patients (Table 39) because of the primary indication of vasospasm. In all 6 there was evidence of intense persistent vasospasm in the affected limb and additionally, in 3, a longstanding history of a pronounced tendency to vasospasm in all the extremities. The results in these 6 patients, and in a number of patients with vasospasm in other categories, furnish evidence of the benefits to be secured by sympathectomy performed upon the indication of vasospasm. In all instances the hand or foot remained warm and the color good after surgical cure of the aneurysm or fistula. In several patients tests for collateral circulation showed it to be only fair before sympathectomy and good following the procedure.

Miscellaneous Indications

In 2 patients (Table 40) sympathectomy was carried out chiefly because of causalgia. In 1 patient (Case 56) prompt and complete relief was experienced. In the other (Case 57), the patient reported "about 90 percent" relief. As a result, it was possible to withdraw rapidly the narcotics to which he was almost addicted. This patient also had a number of other complications, including nerve paralysis, a compound comminuted fracture of the femur, and ulcers and superficial gangrene of the toe and heel. All of these lesions healed and there was adequate circulation in the extremity.

TABLE 39. SYMPATHECTOMY PERFORMED BEFORE OPERATION FOR ANEURYSM OR FISTULA
[Indication—Vasospasm] ¹

Case No.	Location of lesion	Interval between injury and sympathectomy	Interval between sympathectomy and operation	Type of operation	Comment	Results
<i>Cases of Arterial Aneurysms</i>						
49	Femoral.....	Months 3.5	Weeks 2.0	E	Midfoot amputation had been done for trauma; large ulcer, rapid healing after sympathectomy.	Excellent; healed, case suitable for Syme amputation.
<i>Cases of Arteriovenous Fistulas</i>						
50	Femoral.....	7.0	4.5	E	Long history of vasospasm; collateral circulation only fair before, good after sympathectomy.	Excellent.
51	Femoral.....	3.0	7.0	E	Long history Raynaud-like disorder.....	Excellent.
52	Popliteal.....	2.5	7.0	E	Marked vasospasm for years; collateral circulation only fair before sympathectomy.	Excellent.
53	Popliteal.....	3.0	1.0	E	Affected foot remained cold in ordinary room temperature, other warm; ulcer of leg.	Excellent.
54	Foot, cirroid...	Unknown	4.0	E	Cyanosis and coldness of foot had followed excision of posterior tibial A-V; two A-V's remained to be excised, involving peroneal and anterior tibial vessels, one excised at time of sympathectomy, other 4 weeks later; cyanosis and coldness disappeared after sympathectomy.	Good; only difficulty was slow healing of ulcer of foot.

¹ Abbreviation used in this table:
E, Excision.

Another patient (Case 58) had gangrene and infection of all the toes and a compound comminuted fracture of the femur. The gangrenous toes were amputated at the time that the sympathectomy was performed. The end results in this patient were excellent. The fistula was cured through surgical intervention, the fracture healed, the infection cleared, and the patient had a useful limb with excellent circulation.

Three patients (Cases 55, 59, and 60) had peripheral nerve lesions in limbs in which the circulation was obviously impaired or the collateral circulation regarded as only questionably adequate. One of these had in addition an ulcer of the foot. Following sympathectomy, results were good in all three.

In the last patient in the category of miscellaneous indications (Case 61), three previous attempts by other surgeons had failed to effect a cure of an arteriovenous fistula. Both the ulnar and the radial artery had previously been ligated and divided. It seemed likely that important collateral vessels might have to be sacrificed in a radical excision of the cirroid aneurysm which

TABLE 40. SYMPATHECTOMY PERFORMED BEFORE OPERATION FOR ANEURYSM OR FISTULA
[Indication—Miscellaneous]¹

Case No.	Location of lesion	Interval between injury and sympathectomy	Interval between sympathectomy and operation	Type of operation	Comment	Results
<i>Cases of Arterial Aneurysms</i>						
55	Axillary -----	Months 8.0	Weeks 2.0	E	Impaired circulation; extensive plexus injury requiring neurolysis and radial suture.	Excellent.
56	Axillary -----	2.0	12.0	E	Causalgia; relief after sympathectomy -----	Excellent.
<i>Cases of Arteriovenous Fistulas</i>						
57	Femoral -----	1.0	14.0	E	Causalgia, superficial gangrene of toe and heel, peroneal palsy, F. C. C. femur; pain relieved, ulcers healed slowly after sympathectomy.	Excellent.
58	Femoral -----	2.0	16.0	E	Gangrene of toes, multiple fractures of metacarpals, compounded and infected F. C. C. femur; healing after sympathectomy and amputation of toes; fractures healed, infection cleared.	Excellent.
59	Femoral -----	5.0	2.5	E	Impaired circulation and complete sciatic paralysis; nerve suture had been done, ulcer of foot.	Good; ulcer healed, some cold sensitivity.
60	Popliteal -----	2.0	7.0	E	Peroneal paralysis; collateral circulation only fair before sympathectomy.	Excellent.
61	Ulnar, cirsoïd...	Unknown	1.0	E	Had three previous operations with ligation of radial and ulnar arteries and a medial palsy; impossible to foretell what collaterals might have to be sacrificed in a radial excision.	Excellent.

¹ Abbreviations used in the table:

E, Excision.

F. C. C., Fracture compound comminuted.

involved the ulnar aspect of the forearm. Sympathectomy was performed in the hope that it would provide protection against ischemic difficulties. Operative cure necessitated excision of the flexor sublimis muscle and of the extensive vascular channels in and about this muscle. Results were good; circulation in the hand remained excellent.

Errors of Localization

In 7 patients (Table 41) sympathectomy was performed in error because an aneurysm or a fistula was thought, before operation, to involve arteries other than those actually affected. Such tests as could be performed indicated poor collateral circulation in all. In 3 patients (Cases 62, 63, and 64) digital pressure sufficient to still the aneurysm or fistula invariably occluded the over-

TABLE 41. SYMPATHECTOMY PERFORMED BEFORE OPERATION FOR ANEURYSM OR FISTULA
[Patients in Whom Mistake in Localization of the Lesion was Made] ¹

Case No.	Preoperative localization of lesion	Actual location of lesion	Interval between injury and sympathectomy	Interval between sympathectomy and operation	Type of operation	Comment	Results
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Cases of Arterial Aneurysms

			Months	Weeks			
62	Femoral.....	Profunda....	3.0	10.0	A	Compression which stilled aneurysm obliterated femoral pulse; thrombosis and shrinkage occurred after sympathectomy but sac persisted.	Excellent.

Cases of Arteriovenous Fistulas

63	Common femoral..	Profunda....	28.0	10.0	E	Compression which eliminated bruit and thrill stopped femoral pulse.	Excellent.
64	Femoral.....	Profunda....	6.0	8.0	E	Compression which eliminated bruit and thrill stopped femoral pulse.	Excellent.
65	Popliteal.....	Geniculate..	8.0	6.0	E	Bruit and thrill could not be eliminated by pressure without loss of popliteal pulse.	Excellent.
66	Popliteal.....	Posterior tibial.	5.0	6.0	E	A very high posterior tibial lesion; bruit and thrill could not be eliminated by pressure without loss of posterior and anterior tibial pulse.	Excellent.
67	Subclavian.....	Transverse cervical.	4.5	3.0	E	Bruit and thrill could not be stopped by pressure without loss of brachial pulse.	Excellent.
68	Posterior and anterior tibial.	Posterior tibial.	3.5	4.0	E	Bruit and thrill could be stopped only by pressure, which caused loss of anterior and posterior tibial pulses; had tibial paralysis and F. C. C. fibula.	Excellent.

¹ Abbreviations used in this table:
A, Aneurysmorrhaphy or aneurysmotomy with intrasaccular ligation or transfixing of the artery.
E, Excision.
F. C. C., Fracture compound comminuted.

lying femoral as well as the involved profunda femoris artery. In all of these the lesion was, therefore, thought to be in the femoral or common femoral artery. In each case, however, it was found at operation to be in the profunda femoris artery.

In two other patients (Cases 65, 66) the fistula was in such close proximity to the popliteal artery that the bruit and thrill could be eliminated only by digital pressure which compressed the adjacent popliteal artery. In the first patient the lesion was in the geniculate artery and in the second in the posterior tibial artery. In a sixth patient (Case 67) a fistula between the transverse cervical artery and the internal jugular vein could be occluded only by pressure which obliterated the brachial pulse. This fistula was thought therefore to

involve the subclavian vessels. In the remaining patient (Case 68), actually with an arteriovenous fistula of the posterior tibial artery, it was thought that the anterior tibial vessels might also be involved since the fistula could be closed only by compression which occluded the anterior as well as the posterior tibial artery. This patient had an extensive fracture of the fibula and it is likely that it contributed to the difficulty of accurate digital compression.

In all 7 patients tests showed the collateral circulation to be poor before sympathectomy and good afterward. It is apparent, in retrospect, that had correct localization been possible in each of 3 patients, sympathectomy could safely have been omitted. It is also apparent in retrospect that with 1 possible exception (Case 65), arteriograms might have established the correct site of the lesion in all 7.

SYMPATHECTOMY PERFORMED AT THE TIME OF THE VASCULAR OPERATION

In 9 patients (Table 42) sympathectomy was performed at the time that the operation upon the aneurysm or fistula was done. In 1 patient (Case 77) the sympathectomy was carried out primarily because the sympathetic chain was easily exposed in the operative incision through which the iliac artery had

TABLE 42. SYMPATHECTOMY PERFORMED AT THE TIME OF OPERATION FOR ANEURYSM OR FISTULA ¹

Cases of Arterial Aneurysms					
Case No.	Location of lesion	Interval between injury and sympathectomy	Type of operation	Comment	Results
		<i>Months</i>			
69	Popliteal.....	3.0	A	Infected aneurysm ruptured subcutaneously, severe pain.	Excellent.
70	Popliteal.....	3.0	A	Huge aneurysm ruptured subcutaneously, severe pain; collateral circulation nil by reactive hyperemia test before sympathectomy, complete flush in 30 seconds after sympathectomy.	Excellent.
71	Popliteal.....	6.0	E	Following excision of aneurysm, foot cold and blue; circulation still impaired after sympathectomy, but foot warm and pink few hours later.	Ischemic palsy developed; recovery.
72	Popliteal.....	4.0	A	Large, infected mycotic aneurysm with sensory and motor loss in foot and much pain; collateral circulation excellent after sympathectomy.	Excellent; steady recovery from ischemic palsy.
73	Lateral femoral circumflex.	11.0	A	Profunda had been ligated at time of injury; aneurysm could be stilled only by pressure which stopped femoral pulse, collateral circulation nil by reactive hyperemia test before sympathectomy, good flush 30 seconds after sympathectomy.	Excellent.

See footnote at end of table.

TABLE 42. SMYPATHECTOMY PERFORMED AT THE TIME OF OPERATION FOR ANEURYSM OR FISTULA ¹—Continued

Cases of Arteriovenous Fistulas

Case No.	Location of lesion	Interval between injury and sympathectomy	Type of operation	Comment	Results
		<i>Months</i>			
74	Common femoral...	4.5	E	Collateral circulation poor before operation....	Excellent.
75	Femoral.....	3.0	E	Huge aneurysm ruptured subcutaneously, severe pain, tibial and saphenous sensory loss; poor collateral circulation before, good after sympathectomy.	Foot remained warm, well colored; some peroneal sensory loss, perhaps due to tourniquet.
76	Hypogastric.....	5.0	E	External iliac fistula on same side had been excised 7 weeks after injury; collateral circulation poor before, good after sympathectomy.	Excellent.
77	Medial circumflex femoral.	13.0	E	A-V fistula caused by surgical ligation of the femoral artery at time of injury; bruit and thrill could be stopped only by pressure high in femoral area, iliac arteries explored as precautionary measure, sympathectomy done only because chain lay exposed during procedure.	Excellent.

¹ Abbreviations used in this table:
A, Aneurysmorrhaphy or aneurysmotomy with intrasaccular ligation or transfixing of the artery.
E, Excision.

been isolated as a preliminary precaution. The fistula was so high that it was between the medial circumflex femoral artery and the common femoral vein. In another instance (Case 73) sympathectomy might also have been omitted had the fistula been correctly located before the exploration. This patient had a very large aneurysm in the anterior aspect of the thigh which could be stilled only by pressure which occluded the femoral artery. The profunda had been ligated in this patient shortly after injury. Tests showed the collateral circulation to be extremely poor before sympathectomy and excellent afterward. In this case the aneurysm involved only the lateral femoral circumflex artery.

Results were good in 7 of the 9 patients in this group. In 1 patient (Case 75), though the foot at all times after operation was warm and of good color, some peroneal sensory loss without motor involvement was added to the preexisting tibial and saphenous anesthesia. At no time, however, was there evidence of circulatory impairment and it seems likely that this complication was the result of pressure from the tourniquet rather than of postoperative ischemia. In the other patient (Case 71), ischemic paralysis developed after operation. The circulation was obviously impaired for a few hours after operation, but thereafter the limb rapidly regained normal warmth and color. In this patient, sympathectomy and the operation upon the vascular

lesion were performed concomitantly without retesting the collateral circulation following sympathectomy. This precaution should never be omitted.

That it is sometimes advantageous to perform sympathectomy at the same time as the vascular operation is obvious from a consideration of the patients in this group in whom severe pain was present. To illustrate, in 1 patient (Case 70), an extremely large popliteal aneurysm ruptured subcutaneously and was so painful that the patient writhed in agony. Large doses of morphine afforded no relief. The reactive hyperemia test was characterized by a complete absence of flush. Sympathectomy was performed and a complete and intense flush was present within 30 seconds after release of the constricting cuff. Aneurysmorrhaphy was therefore done at once. The patient was entirely comfortable after operation and there was excellent circulation in the foot.

SPECIAL EFFECTS OF SYMPATHECTOMY

Exercise Tolerance and Cold Sensitivity

Two functional disorders which commonly follow the ligation of an artery for the cure of an aneurysm or a fistula are decrease in exercise tolerance, and sensitivity of the limb to cold. Since reduction in exercise tolerance is particularly noticeable after ligation of the popliteal, femoral, and common femoral arteries, a consideration of the effect of sympathectomy upon intermittent claudication or its equivalent is best limited to patients with lesions of these vessels. In addition, certain other patients should be excluded from any study of exercise tolerance: (1) those patients who had difficulty walking prior to sympathectomy because of fractures, amputated digits or parts of limbs, or motor loss from peripheral nerve injury, (2) those patients who were unable to walk any distance before operation, and this at a time when the continuity of the blood flow through the affected artery was uninterrupted, and (3) those patients whose arterial lesions were successfully repaired and continuity of the blood flow preserved.

Exercise tolerance in the lower extremity was determined by having the patient walk at a normal pace with a pedometer, or over a measured course, until he was forced to stop because of fatigue or, occasionally, cramps in the limb. The distance walked was approximately the same in the two groups. Patients whose operations had required ligation of the popliteal artery and upon whom sympathectomy had not been done were forced to stop after they had walked an average of 0.68 mile, while those who had had sympathectomy performed could walk 0.73 mile. When ligation of the femoral or the common femoral artery had been necessary, the distance covered was the same (an average of 0.73 mile) regardless of whether sympathectomy had or had not been done.

These data seem to demonstrate that exercise tolerance was almost precisely the same regardless of whether or not sympathectomy was performed.

The two groups, unfortunately, were not carefully controlled from several important standpoints. The time interval between operation and final walking test varied from patient to patient. This is an important factor since some patients reached their maximum tolerance rapidly, others more slowly. It proved impossible to analyze the intensity of the exercise pain in some of the patients. Exaggeration was always a possibility in those who desired to avoid duty and be separated from the service. Finally, the two groups were not entirely comparable because from the various tests and observations it was evident that the collateral circulation was more efficient in the group in which sympathectomy was considered unnecessary.

More clear-cut information is available concerning the effect of sympathectomy in the prevention of sensitivity of the limb to cold after operation. Sensitivity to cold of varying degrees was a complaint of 5 of 18 patients upon whom sympathectomy had been done. In these patients the continuity of the subclavian, axillary, or brachial arteries had been interrupted either through ligation or reparative procedures which failed. In 31 patients with popliteal or femoral lesions treated similarly, only 1 complained of sensitivity to cold. Two of the 6 patients who complained had this sensitivity before operation.

In contrast, cold sensitivity was a complaint of 13 of 40 patients upon whom sympathectomy had not been done. In these patients the continuity of the subclavian, axillary, or brachial arteries had been interrupted. In 65 patients with popliteal or femoral lesions treated similarly, 5 complained of sensitivity to cold. Eight of the 18 patients who complained had this sensitivity prior to operation.

Sensitivity to cold was a complaint of 14 patients with aneurysms or arteriovenous fistulas who were received at the Mayo General Hospital after they had been operated on at other installations (see Part II this chapter). There were 5 such complaints in 11 patients with lesions of the main arteries of the upper extremity, and 9 in 30 patients with lesions of the main arteries of the lower extremities. None of the patients who complained of cold sensitivity after operation had been treated by sympathectomy. A single patient in this group had had sympathectomy performed at the time of the vascular operation. He did not complain of sensitivity to cold.

Altogether, of the 50 patients upon whom sympathectomy had been performed prior to an operation which resulted in interruption of the main arterial stem to the extremity, 6 complained of sensitivity to cold (12 percent). In contrast, of 146 patients who had similar operations without sympathectomy, 32 complained of cold sensitivity (21.9 percent).

Intrasaccular Thrombosis

Not uncommonly sympathectomy was followed by a noticeable increase in the mural thrombus within the aneurysmal sac. Sometimes this process was very extensive. In one patient, for example (Case 62), a large pulsating aneurysm

in the thigh became progressively smaller and firmer after sympathectomy and eventually lost its pulsation entirely. Clinically it appeared that the lesion had been completely obliterated, but arteriograms revealed the persistence of a sac several centimeters in diameter. At operation the laminated mural thrombus was found to be many times larger than the remaining aneurysmal cavity.

In 2 other patients cures of this type occurred. The first patient (Case 27) had a pulsating femoral aneurysm about 7 cm. in diameter. Tests of the collateral circulation gave evidence of its complete inadequacy. Sympathectomy was performed 2 months after injury. After this procedure the aneurysm became by degrees somewhat firmer and smaller and pulsated less vigorously. The process was slow during the first few months but finally, 6 months after sympathectomy, only a small, firm, nonexpansile mass remained. Arteriograms revealed almost complete obliteration of the sac. During the next few weeks this mass practically disappeared and it was evident that a satisfactory cure had been obtained.

In the second patient (Case 47) there were signs suggestive of an arteriovenous fistula of the proximal portion of the left subclavian vessels. After sympathectomy the thrill and continuous bruit disappeared and only a short systolic bruit remained. The extra-mediastinal portions of the vessels were explored in the belief that a saccular aneurysm remained. No aneurysm was found, and there was such dense scarring about the vessels as the mediastinum was approached that exploration was discontinued on the assumption that the remaining systolic bruit was probably the result of partial compression of the artery by scar tissue.

In evaluating the results of sympathectomy in this group it must be borne in mind that spontaneous cure occurs occasionally without operation in both arterial aneurysm and arteriovenous fistula (see Chapter XII). It took place in 11 of the 224 patients in this particular series upon whom sympathectomy was not done (4.9 percent). On the other hand, a cure by thrombosis occurred in but 2 of the 77 patients upon whom sympathectomy was performed (2.6 percent). It is difficult, therefore, to be certain that thrombosis in these patients was actually the result of sympathectomy. The decision is particularly difficult when complete thrombosis occurs gradually and over a long period of time, as happened in 1 patient (Case 27). When it occurs promptly after sympathectomy as in some of the cases recorded in the literature, the march of events seems to suggest that it has resulted from sympathectomy. The cause-and-effect relationship seems all the more likely because of the incomplete thrombosis of the sac which is commonly observed after sympathetic denervation.

The question arises whether an increase in mural thrombosis or complete thrombosis of the sac can be associated with extension of the clot distally. The course of a patient in the author's experience in civil practice suggests that, uncommon as the occurrence may be, it can take place.

CASE REPORT

The patient was a 49-year-old man with an arteriosclerotic aneurysm of the right popliteal artery. When he was admitted to the hospital the aneurysm pulsed vigorously and there was a loud systolic bruit. There was also evidence of peripheral arteriosclerosis. On the affected side the dorsalis pedis pulse was present but the posterior tibial, absent. Both pulses were present in the left foot. The collateral circulation was very poor. Although these findings were checked the day before sympathectomy was performed, the pulses, unfortunately, were not palpated nor were oscillometric studies made immediately before operation. The day after sympathectomy the aneurysm was observed to be somewhat firmer and there was only a faint, shock-like sound in place of the systolic bruit previously heard. The dorsalis pedis pulse had disappeared and oscillometric studies confirmed the impression that the popliteal artery was occluded distal to the aneurysm. This impression, as well as the fact of a recent increase in the extent of mural thrombus, was verified at operation 8 days later. Although no proof exists in this case, the evidence suggests that the extension of the mural thrombus following sympathectomy brought about occlusion of the artery distal to the aneurysm. An excellent result followed aneurysmorrhaphy.

COMMENT

Effects of Sympathectomy

In considering the role of sympathectomy as an adjuvant measure in the surgical treatment of aneurysms and arteriovenous fistulas, it is important to keep in mind that in the hands of those familiar with it, this procedure is associated with minimal risk and very little discomfort. Patients can be ambulatory the day after either dorsal or lumbar sympathectomy. In the experience at the Mayo General Hospital there were no deaths and complications were extremely uncommon.

Data derived from the tests given the patients in this series supply convincing evidence that sympathectomy is useful in rendering the collateral circulation more efficient by eliminating vasoconstriction in the collateral vessels. This is exemplified by the fact that following sympathectomy the hand or foot was almost always of excellent warmth and color in patients in whom cure of the vascular lesion entailed arterial ligation. It is even more strikingly exemplified by the remarkable improvement in the collateral circulation which so often occurred immediately after sympathectomy was carried out. These data do not offer convincing proof that sympathectomy actually increases the collateral circulation by fostering the growth of new collateral channels. However, data derived from tests made on these patients in whom the collateral circulation showed only slight improvement immediately after sympathectomy, but steady significant improvement during the ensuing weeks and months might suggest that sympathectomy had this effect. Perhaps a more plausible explanation, however, would be simply progressive dilatation of existing collaterals. In contrast it is noteworthy that in a number of patients upon whom sympathectomy was not performed, tests showed that the circulation had improved during short periods of observation.

The immediate effect of sympathectomy upon the status of the collateral circulation can be predicted with reasonable accuracy by comparing the results of the reactive hyperemia test in any given patient under ordinary environmental conditions with those obtained during reflex vasodilatation with the patient under anesthesia or, better still, after sympathetic block with procaine. Such studies are unnecessary as routine measures, however, and one can proceed with sympathectomy without additional testing in any case in which the indications are plain. Should the preoperative tests for collateral circulation show it to be poor and should no distinct improvement follow sympathectomy, the situation should be considered sufficiently precarious to warrant the use of all additional measures which might add some safeguard against ischemic difficulties. These include intermittent occlusion of the artery, delay in operative treatment, and efforts to preserve the continuity of the artery at the time of operation.

The Rationale of Sympathectomy

The Mayo General Hospital experience indicates that a rational plan for the use of sympathectomy in aneurysm or arteriovenous fistula can best be formulated on the basis of the various indications for its use.

Inadequate Collateral Circulation. Sympathectomy seems indicated when there is evidence of poor collateral circulation provided the lesions are of sufficient duration to have produced under ordinary circumstances good collateral circulation, and provided the simpler means of improving the collateral circulation have shown no results during a short period of trial. The literature is full of statements concerning results of intermittent proximal occlusion of the affected artery on the collateral circulation and in some instances there is clear evidence that such an effect has been achieved. In many patients, however, it is difficult to see any beneficial results. It would be a significant contribution to the problem of the treatment of aneurysms and arteriovenous fistulas if controlled experimental and, preferably, clinical studies should establish beyond question the value and limitations as well as the criteria for continuing or abandoning such procedures. From the experience at this center it would seem that sympathectomy is indicated if there is no definite improvement in the collateral circulation following such efforts as intermittent proximal occlusion of the affected artery carried out over a period of some weeks. It has been established that permanent partial occlusion of the proximal artery is sometimes helpful in increasing the collateral circulation in instances of arterial aneurysm, but this procedure is not applicable in instances of arteriovenous fistula.

Since sympathectomy is as simple as partial proximal ligation and probably safer, and since partial proximal ligation may jeopardize the chances of successfully maintaining or reestablishing the continuity of the involved artery when the major operation is attempted, sympathectomy seems to be the wiser procedure in arterial aneurysms in which the collateral circulation does

not appear to be adequate. In the majority of instances in this series in which sympathectomy was carried out because the results of tests showed the collateral circulation to be unsatisfactory, improvement was noted fairly promptly. Even in the instances in which the tests did not show the circulation to be entirely adequate following sympathectomy, the procedure at least assured the surgeon that vasoconstriction had been eliminated.

Associated Peripheral Nerve Lesions. When the aneurysm or arteriovenous fistula is associated with a peripheral nerve lesion which requires operative treatment, a precarious collateral circulation seems a clear-cut indication for sympathectomy. It is imperative that the nerve lesion be treated as promptly as possible and it is entirely too hazardous to attempt nerve repair before operative cure of the aneurysm or fistula has been achieved. Any effort to improve the collateral circulation and permit early operative treatment both of the arterial and the nerve lesion is therefore worthwhile.

Sympathectomy would seem to be indicated particularly when the combined vascular-nerve lesion is associated with obvious evidence of impaired circulation in the extremity regardless of whether or not the collateral circulation appears to be adequate. In such cases it must be assumed that operative cure of the vascular lesion may require ligation of the artery and further reduction in the circulation of the limb. Furthermore, an adequate vascular supply fosters nerve regeneration exactly as impairment of the circulation may produce ischemic nerve injury. The data in this series are insufficient for a quantitative comparison of nerve regeneration in patients with unimpaired circulation and those with impaired circulation upon whom sympathectomy was done. The impression seems warranted, however, that nerve regeneration was comparable in the two groups. The data do offer conclusive proof that sympathectomy may be of great benefit in instances of ischemic nerve injury with impaired circulation resulting from arterial ligation, division, or thrombosis.

Collateral Circulation Undeterminable. When the anatomic location of the aneurysm or fistula is such that digital occlusion of the artery is not possible, sympathectomy seems advisable if the artery affected is one in which ligation is sometimes followed by ischemic difficulties. When the artery cannot be compressed precisely at the site of the defect, proximal or distal compression may reveal some information concerning the state of the collateral circulation. It must be borne in mind, however, that tests of this kind may supply erroneous information either because collateral channels which can be preserved during the operative procedure are occluded, or because the reverse is true and channels which may have to be sacrificed have not been occluded.

Ischemic Lesions. When ischemic lesions are present distal to an aneurysm or a fistula, sympathectomy is indicated since cure of the vascular lesion may entail ligation of the artery thereby still further reducing the circulation. Even if the blood flow through the artery can be preserved, increase in the circulation would be highly desirable since the ischemic lesion supplies unequivocal evidence of insufficiency.

Vasospasm. If the main artery to a limb must be ligated for the cure of a vascular lesion, the surgeon cannot afford to take the chance of having the remaining circulation jeopardized by vasospasm in the collateral vessels. Vasospasm, of course, is not present in every limb in which a main arterial stem is ligated. Indeed, the vascular tone after ligation may be high, low, or normal. In some patients the limb actually exhibits evidence of vasodilatation and increased stability of skin temperature under varying environmental circumstances; these findings suggest the effect of periarterial sympathetic interruption consequent to ligation and division of the artery. Whenever there is evidence of pronounced vasospasm it appears unwise to run the risk of its occurrence after operation. Such a problem might be handled in two ways: (1) Proceed with the operation and then if alarming vasospasm ensues attempt to control it by sympathetic blocks or, if necessary, by sympathectomy. (2) Perform sympathectomy either before the vascular operation or at the same time, even though tests for collateral circulation show it to be good. This is the safer method and one to be recommended in instances in which intense vasospasm is already present.

Miscellaneous Indications. Sympathectomy may be required in the occasional patient in whom one or more of the main arteries to a limb have already been occluded by previous injury or operation and in whom cure of an aneurysm or fistula may require ligation of other arteries essential to nutrition and proper function. Similarly, an occasional patient will be encountered in whom an aneurysm or fistula is associated with severe causalgia which can be temporarily relieved, though not cured, by sympathetic blocks.

Unnecessary Sympathectomy. Sympathectomy should not be performed unless there is some specific indication for its use, and even if the indications listed are strictly adhered to as a basis for the employment of the operation it will undoubtedly be performed in certain instances in which it might safely have been omitted. These instances occur chiefly when, during operation, it is found possible to maintain the continuity of blood flow through the affected artery by some reparative procedure. Since, however, the feasibility of such procedures cannot be foreseen, and since one cannot always be sure that the repair will be successful, it is wise to make certain that the collateral circulation is adequate before an attempt is made to extirpate an aneurysm or fistula. In practice, adherence to this policy will mean the performance of an occasional unnecessary sympathectomy.

Sympathectomy is sometimes done needlessly because of improper localization of the aneurysm or fistula. Fortunately, this seldom happens. Difficulties are most often encountered in lesions located high in the profunda femoris artery in which digital pressure sufficient to still an aneurysm or abolish the bruit and thrill of a fistula is likely to compress the overlying femoral artery. In such cases arteriograms will ordinarily establish the correct location of the lesion.

Even though preliminary sympathectomy is not performed, numerous patients will recover from operative cure of an aneurysm or fistula with no signs of gangrene or ischemic paralysis. When, however, such serious complications appear to offer a definite threat, it seems wise to take every precaution to avoid them, even at the risk of performing an unnecessary operation. One cannot afford to gamble with the viability of an arm or a leg. Indeed, as the reported series of cases illustrates, such disasters may occur even if sympathectomy is performed. It should be emphasized that sympathectomy offers no guarantee that some ischemic difficulty may not occur after ligation of an important artery: Sympathectomy must therefore be looked upon as an aid in, but not as a sure preventive of, ischemic troubles. Furthermore, the utmost care in testing the collateral circulation and in avoiding injury to collateral vessels at the time of operation must be exercised or sympathectomy will be associated at times with disastrous results.

Exercise Fatigue and Cold Sensitivity. Fatigue on exercise and sensitivity to cold are two symptoms which commonly occur in limbs following the operative cure of aneurysm or arteriovenous fistula even though circulation to the limb is otherwise adequate. As already pointed out, although no definite conclusions can be formulated in regard to exercise fatigue, the results in the series of patients observed at the Mayo General Hospital give the impression that sympathectomy seldom has any marked beneficial effect upon exercise tolerance. The results of sympathectomy are more clear-cut in respect to cold sensitivity. Though this complication sometimes occurs following arterial ligation in patients upon whom sympathectomy has been performed it occurs far more frequently in those upon whom sympathectomy has not been carried out.

Intrasaccular Thrombosis. As Gage⁸ noted in his original publication, intrasaccular thrombosis frequently occurs following sympathetic denervation in instances of arteriovenous fistulas. DeBakey⁹ recorded a case of carotid-cavernous sinus fistula in which cure by thrombosis occurred after sympathectomy, and Colsen and Giddy¹⁰ noted progressive thrombosis of the aneurysmal sac within a few days after they had performed lumbar sympathectomy in preparation for exploration of a popliteal aneurysm. In the latter case an apparently satisfactory cure was obtained without operative treatment. In this series of patients extension of the mural thrombus within the sac was often noted following sympathectomy and in two instances apparent cure by thrombosis followed interruption of the sympathetic pathways. Since spontaneous cure by thrombosis occurs occasionally without sympathectomy it is impossible to state that a cause-and-effect relationship exists when a cure by thrombosis

⁸ See footnote 1, p. 318.

⁹ Martin, J. D., Jr., and Mabon, R. F.: Pulsating exophthalmos; review of all reported cases. *J. A. M. A.* 121: 330-335, 30 Jan 43. (Discussion by Ochsner.)

¹⁰ Colsen, K., and Giddy, P.: Popliteal aneurysm cured by lumbar ganglionectomy. *South African M. J.* 18: 242, 22 Jul 44.

follows the operation, although there is evidence which suggests that this is true.

Sympathectomy Combined with Operation on the Vascular Lesion. Sympathectomy and the vascular operation need not be performed as separate procedures. They can undoubtedly be combined more often than was done in the present series of cases. Unless there is evidence of an unquestionably adequate collateral circulation before operation, the procedure at operation should be (1) to perform sympathectomy, (2) to test the collateral circulation, and (3) to proceed with, or abandon, the contemplated operative attack upon the vascular lesion according to the results of these tests.

Part II. Postoperative Sympathectomy

The usefulness of sympathectomy in increasing the efficiency of the collateral circulation, in providing maximal or near-maximal circulation in an injured limb, in favorably influencing existing ischemic difficulties, and in alleviating such associated conditions as causalgia, made it reasonable to suppose that it might also be of benefit in correcting certain circulatory conditions which sometimes follow the surgical treatment of aneurysms and fistulas. Similarly, experience with sympathectomy in other disorders in which blood flow through an important artery had been interrupted by disease, injury, or operation suggested that this procedure would be of value in correcting these conditions.

At the vascular center of Mayo General Hospital certain generalizations concerning circulatory disorders following surgical treatment of aneurysms and fistulas were confirmed: Circulatory disorders can be lessened if tests for the efficiency of the collateral circulation are used as a guide in the selection of the proper time for operation and if operative techniques are employed which in no way injure the collateral blood supply. In addition, these disorders can practically be eliminated if the continuity of the blood flow through the involved artery can be maintained or restored by some reparative procedure. Nonetheless, circulatory disorders occur occasionally in spite of all efforts to avoid them, and this chapter is a report of a study made at this center on the value of postoperative sympathectomy in correcting such disorders.

CLINICAL MATERIAL¹¹

In addition to the 75 sympathectomies performed upon 288 patients either before or during the course of operation for aneurysms and arteriovenous fistulas, and the 2 performed upon 13 patients in whom cure by thrombosis occurred and surgical intervention proved unnecessary, 19 sympathectomies were performed after operation in the 213 patients in whom preoperative sympathectomy had not been performed. (Table 43.)

¹¹ See footnote 5, p. 320.

TABLE 43. INCIDENCE OF SYMPATHECTOMY IN PATIENTS WITH ARTERIAL ANEURYSMS AND ARTERIOVENOUS FISTULAS

Category of patient	Total lesions	Sympathectomies performed					
		Total		Preoperative ¹		Postoperative	
		Number	Percent	Number	Percent	Number	Percent ²
Operated upon at Mayo General Hospital:							
Aneurysm.....	82	36	43.9	28	34.1	8	14.8
Arteriovenous fistula.....	206	58	28.2	47	22.8	11	6.9
Total.....	288	94	32.6	75	26.0	19	8.9
Operated upon elsewhere:							
Aneurysm.....	29	12	41.4	1	3.4	11	39.3
Arteriovenous fistula.....	34	8	23.5		0	8	23.5
Total.....	63	20	31.7	1	1.6	19	30.6
With Nonsurgical Cures (Thrombosis):							
Aneurysm.....	³ 8	1	12.5	1	12.5		0
Arteriovenous fistula.....	5	1	20.0	1	20.0		0
Total.....	13	2	15.4	2	15.4		0
Combined Series:							
Aneurysm.....	119	49	41.2	30	25.2	19	21.3
Arteriovenous fistula.....	245	67	27.3	48	19.6	19	9.6
Total.....	364	116	31.9	78	21.4	38	13.3

¹ In this group are included the sympathectomies performed at the time of operation.
² Percent of lesions not involving preoperative sympathectomy.
³ An additional patient was sent to this center. Neurosurgery was required, and at time of operation it was discovered that spontaneous cure of an aneurysm by thrombosis had occurred. Following neurosurgery sympathectomy was performed. This patient is included in the category of those treated elsewhere.

Sixty-two patients were admitted to the Mayo General Hospital after operation elsewhere for aneurysms and arteriovenous fistulas (Table 43), 43 of which had been performed overseas. Upon 19 of the 62 patients sympathectomy had been performed, 1 before and 18 after vascular surgery. In addition there was one other admittance of a patient, in whom spontaneous cure of the vascular lesion had occurred (Case 82, Table 44), and upon whom sympathectomy was performed after neurosurgery.

The clinical material thus amounted to 116 patients; in 76 sympathectomy was carried out before or in the course of vascular surgery, in 37 after vascular surgery, and in 3 the vascular operation was not necessary because spontaneous cure by thrombosis occurred (Table 43).

Although the proportion of sympathectomies was essentially the same in the patients operated on at Mayo General Hospital (32.6 percent) and in those operated on elsewhere (31.7 percent), a breakdown of the figures discloses significant differences (Table 43). Sympathectomy was carried out before or at the time of the vascular operation in 26.0 percent of the patients of

Mayo General Hospital, but in only 1.6 percent of the patients operated on elsewhere. The incidence of postoperative sympathectomy at Mayo General Hospital in the 213 patients upon whom sympathectomy had not earlier been performed was 8.9 percent, against 30.6 percent in the patients operated on elsewhere. In both groups the indication for sympathectomy was proportionately more often aneurysm than arteriovenous fistula (Table 43).

The 38 postoperative sympathectomies were performed upon 19 patients with aneurysms and 19 with arteriovenous fistulas. The upper extremities were involved in 17 patients and the lower in 21. In 3 patients (Cases 105, 106, and 107, Table 47) sympathetic interruption was achieved by means of alcohol injection. In the remainder it was brought about by surgical excision of the sympathetic pathways. Ganglionectomy was used when the lower extremities were involved, the approach being through an anterior extra-peritoneal incision. The Smithwick type of preganglionic operation was done when the upper extremities were affected.

There were no deaths in the 38 patients and no serious complications resulted.

INDICATIONS FOR POSTOPERATIVE SYMPATHECTOMY

The chief indications for postoperative sympathectomy in these 38 patients were (1) distressing sensitivity of the limb to cold, (2) associated severe peripheral nerve damage in limbs in which the circulation was definitely impaired, (3) persistent edema, (4) ischemic nerve paralysis, (5) causalgia relieved temporarily but not cured by sympathetic blocks, (6) obviously impending gangrene, and (7) evidence of sympathetic overactivity, with or without poor collateral circulation, in a limb in which another arteriovenous fistula required excision. The data concerning the 38 patients are summarized in Tables 44 through 47, grouped according to the primary indication for sympathectomy. In many instances, however, there were several circumstances which influenced the decision to perform sympathectomy.

Cold Sensitivity. The largest number of postoperative sympathectomies, 17, was performed because of sensitivity of the affected limb to cold (Table 44). Nine patients in this group had arterial aneurysms and 8, arteriovenous fistulas. In 9 the upper extremity was involved and in 8 the lower extremity. In 1 patient (Case 82, Table 44) cure of the aneurysm by spontaneous thrombosis had occurred; in the others excision of the lesion had been necessary. The duration of the lesion at the time of the vascular operation ranged from 1 to 4 months and averaged about 1½ months in the group operated upon overseas; the range was from 2.5 to 11 months and averaged about 5½ months in those operated upon at Mayo.

All of the patients in this group had annoying coldness of the affected hand or foot upon exposure to cold and most of them had cyanosis, mild in some instances and severe in others. Some patients described the sensation as

aching, others as burning or tingling. Most of them had some degree of numbness of the fingers or toes and nearly all of them complained of stiffness of the digits. When paresis was present it was aggravated during exposure to cold, and pain, paresthesia, or hypesthesia also tended to become more intense. The affected hand or foot was generally warm and of good color in a warm environment. One patient (Case 91, Table 44), for example, always had a warm, well-colored foot under ordinary circumstances and showed no evidence of circulatory insufficiency except for the usual fatigue on exercise which was

TABLE 44. SYMPATHECTOMY PERFORMED AFTER OPERATION FOR ANEURYSM AND ARTERIO-
VENOUS FISTULA

Cases of Arterial Aneurysms
[Indication—Cold Sensitivity]¹

Case No.	Location of lesion	Interval between injury and operation	Interval between operation and sympathectomy	Type of operation	Comment	Results
		<i>Months</i>	<i>Months</i>			
78	Axillary.....	5.0.....	1.5	E	Also severe plexus injury, circulation impaired.	Relief, circulation improved; nerve return satisfactory except for radial; tendon transplant.
79	Brachial.....	6.0.....	0.5	E	Also mild causalgia, median palsy, circulation impaired.	Relief, circulation improved, causalgia largely relieved; nerve return satisfactory.
80	Brachial.....	7.5.....	0.5	E	Cold sensitivity before and after operation, ulnar palsy.	Relief, nerve return satisfactory.
81	Brachial.....	7.0.....	1.0	E	Median palsy.....	Much improved, satisfactory nerve return.
82	Brachial.....	Spontaneous cure 1.5 Excision thrombosed artery 6.0	6.0	E Thrombosed artery.	Also median palsy, neurolysis.....	Relief, excellent return of nerve function.
83	External iliac.	11.0.....	1.0	E	Also frostbite, marked C. S. with pain and hypesthesia.	C. S. persisted though considerably lessened, burning persisted.
84	Femoral.....	1.0.....	6.0	2 E	Marked C. S.....	Relief.
85	Femoral.....	1.0.....	5.0	2 E	.....	Relief.
86	Popliteal.....	1.0.....	6.5	2 E	Sciatic palsy, pain in foot.....	Relief, pain lessened.

See footnotes at end of table.

TABLE 44. SYMPATHECTOMY PERFORMED AFTER OPERATION FOR ANEURYSM AND ARTERIOVENOUS FISTULA—Continued

Cases of Arteriovenous Fistulas[Indication—Cold Sensitivity]¹—Continued

Case No.	Location of lesion	Interval between injury and operation	Interval between operation and sympathectomy	Type of operation	Comment	Results
		<i>Months</i>	<i>Months</i>			
87	Subclavian	4.0	5.0	² E	Extreme C. S., fatigability	Relief.
88	Subclavian	4.0	2.0	E	Marked C. S., fatigability	Relief.
89	Subclavian	3.0	2.0	E		Relief.
90	Brachial	2.0	2.0	E	Marked C. S., vasospasm, pain aggravated by cold exposure, ulnar palsy; fistula discovered during neurosurgical exploration.	Relief, pain relieved.
91	Femoral	2.5	3.0	E	Marked C. S.	Relief.
92	Femoral	2.0	4.0	² E		Relief.
93	Femoral	1.0	3.5	² E		Relief.
94	Femoral	1.0	5.0	² E	Partial sciatic paralysis, pain in foot.	Relief, pain lessened.

¹ Abbreviations used in this table:

E, Excision.

C. S., Cold sensitivity.

² Operation performed overseas.

a problem with all such patients. He lived in Minnesota, however, and on exposure to cold his foot became icy cold and numb, and ached severely. Since there was no improvement in this condition over a period of months, he decided to have sympathectomy performed. Complete relief followed sympathetic ganglionectomy.

It was the practice to test each patient's ability to withstand exposure to cold. If only mild manifestations of sensitivity were present, sympathectomy was withheld. It was occasionally withheld even when more pronounced, but this was because the patient planned to live in a warm climate and it was felt that the condition would cause little discomfort or disability. However, if the patient planned to live in a cold climate, symptoms of the same degree, were considered an indication for sympathectomy. The situation was always carefully explained to the patient and he was allowed to compare the reaction of the limb to a cold environment under ordinary circumstances and following sympathetic block produced by procaine. After this experience, he was offered the opportunity to elect operation. An occasional patient felt that his work, avocations, and general interests would make prolonged exposure to outside cold unnecessary. The great majority, however, chose to have sympathectomy performed. The advice of fellow patients who had obtained relief from similar complaints undoubtedly influenced the choice of many.

Eight of the 17 patients in this group had, in addition to cold sensitivity, associated peripheral nerve lesions. A few showed evidence of sympathetic overactivity under ordinary environmental conditions, and in 1 instance the vasospasm was rather pronounced. In several patients there was obvious evidence of impaired circulation. One patient had mild causalgia. One had fairly severe frostbite of both feet which resulted from exposure at the time of injury. The injury produced an aneurysm of one external iliac which was treated by excision of the lesion and division of the affected artery. The frostbite continued to cause cold sensitivity in this patient, but the discomfort was much more severe in the limb in which the artery had been divided.

Results of sympathectomy in this group of patients with associated peripheral nerve lesions were excellent. All except 2 obtained full relief, and these 2 experienced definite if not complete relief. The patient who suffered from causalgia gained considerable relief of pain; pain was also relieved in all other instances in which it had been present except in the patient with frostbite who continued to have mild burning in the foot. Nerve regeneration in these patients was as satisfactory as could be expected in the light of the trauma which had been sustained.

Peripheral Nerve Damage. Sympathectomy was performed after operation in 5 patients (Table 45) who, in addition to severe nerve damage, showed evidence of reduced blood flow. One patient had markedly impaired circulation, 1 had extreme hyperesthesia of the hand, and 2 had some sensitivity to cold in the affected part.

In almost every instance sympathectomy had been considered before operation but had been deferred because of evidence of excellent collateral circulation and in the hope that the damage to the nerve might prove to be caused in large part by pressure of the aneurysm or otherwise to be less severe than had been anticipated. In all five patients the neurologic condition observed at operation was worse than had been expected.

The results of sympathectomy in all of these patients were extremely gratifying. Signs of nerve regeneration indicated progress as satisfactory as might have been hoped for, considering the extent of the initial damage. The circulation in each of the limbs was visibly improved and sensitivity to cold relieved or reduced.

Persistent Edema. In 5 patients (Table 46) the indication for postoperative sympathectomy was persistent edema. The edema in these patients ranged from moderate to massive. All had failed to improve under such conservative measures as rest, elevation of the limb, elastic support, and gradually increasing periods of exercise. Sympathetic blocks had resulted in only transient improvement or had produced no effect at all other than temporary warmth and dryness of the foot. All the patients complained of coolness of the affected foot or hyperhidrosis, all had cyanosis, 2 had nerve paralysis, and 1 had indolent ulcers. Two had been operated on overseas when the vascular lesions were, respectively, of 2 weeks and 2 months duration. In the 3 upon whom

TABLE 45. SYMPATHECTOMY PERFORMED AFTER OPERATION FOR ANEURYSM AND ARTERIOVENOUS FISTULA

[Indication—Reduced Blood Supply and Severe Nerve Damage]¹

Case No.	Location of lesion	Interval between injury and operation	Interval between operation and sympathectomy	Type of operation	Comment	Results
<i>Cases of Arterial Aneurysms</i>						
95	Subclavian	Months 2.5	Months 0.5	A	Severe plexus damage, no surgical repair possible; causalgia relieved after operation.	Circulation much improved; good nerve return except for posterior cord; comfortable.
96	Axillary	2.5	1.0	A	Extensive plexus damage, circulation impaired, much sensitivity of hand.	Hypersensitivity of hand relieved, some immediate nerve return, subsequent satisfactory progress.
97	Brachial	1.0	1.5	² E	Had neurolysis of ulnar and suture median nerve, some C. S.	C. S. relieved, satisfactory nerve return, circulation improved.
<i>Cases of Arteriovenous Fistulas</i>						
98	Axillary	6.5	0.5	E	Had neurolysis of brachial plexus and ulnar neurorrhaphy.	Circulation excellent; good nerve return.
99	Axillary	5.0	1.0	E	Had neurolysis of plexus and suture of posterior cord, also some C. S.	Circulation better; slight C. S. remained, nerve return satisfactory.

¹ Abbreviations used in this table:

A, Aneurysmorrhaphy or aneurysmotomy with intrasaccular ligation or transfixing of the artery.

E, Excision.

C. S., Cold sensitivity.

² Operation performed overseas.

the operation was carried out at Mayo General Hospital the lesions were of 2, 3, and 6 months duration.

Results were excellent in 3 patients, moderately good in 1, and fair in another. In addition to the good effect which sympathectomy had upon the edema, warmth and normal color prevailed in all the limbs treated, and satisfactory return of nerve function took place.

Miscellaneous Indications. Sympathectomy was performed upon 11 patients for miscellaneous indications (Table 47). Six of these patients had arterial aneurysms and 5, arteriovenous fistulas.

Ischemic paralysis was the primary indication for sympathectomy in 3 patients (Cases 105, 111, and 112). In 2 of these (Cases 111 and 112) neurologic difficulty followed operations for the cure of femoral arteriovenous fistulas.

The clinical records accompanying the patients contained no data concerning the state of the collateral circulation before operation. One patient (Case 111) had an extensor paralysis of two toes, anesthesia of the foot, and stocking hypesthesia almost up to the knee. Sympathectomy was performed and improvement observed almost immediately. He continued to improve during the ensuing weeks. When last observed motor power had returned to his toes, hypesthesia had disappeared from his leg, and his foot, although still hypesthetic, was no longer anesthetic. The other patient (Case 112) had a stocking anesthesia with complete sciatic paralysis after operation. Return of function in the tibial nerve had been prompt after repair of the vascular lesion, but when he was admitted to the Mayo General Hospital he had complete peroneal motor loss and almost complete sensory loss. The neurologic condition seemed stationary. Sympathectomy was performed and within a few days return of peroneal function was noted. He improved steadily thereafter and complete recovery ensued.

TABLE 45. SYMPATHECTOMY PERFORMED AFTER OPERATION FOR ANEURYSM AND ARTERIOVENOUS FISTULA

[Indication—Edema] ¹

Case No.	Location of lesion	Interval between injury and operation	Interval between operation and sympathectomy	Type of operation	Comment	Results
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Cases of Arterial Aneurysms

		Months	Months			
100	Popliteal	0.5	2.5	² A	Marked edema; cyanosis of foot, ulcers of leg, peroneal palsy, tibial palsy, questionably due to postoperative ischemia.	Marked improvement, edema minimal, ulcers healed.

Cases of Arteriovenous Fistulas

101	Popliteal	3.0	0.5	E	Saccular aneurysm as well as A-V fistula; subcutaneous rupture caused peroneal palsy; after operation fairly marked edema, foot cool.	Marked improvement, foot warmer, edema much less—subsequently disappeared, good nerve return.
102	Popliteal	6.0	1.0	E	Marked edema, foot cool	Edema lessened, foot warm.
103	Posterior tibial.	2.0	1.0	E	Moderate edema, some coolness, cyanosis, and hyperhidrosis; temporary relief and reduction in edema from sympathetic blocks but no lasting effect.	Edema almost completely disappeared, foot warm and well colored.
104	Posterior tibial.	2.0	6.0	² E	Persistent edema, some cyanosis of foot . . .	Edema considerably lessened.

¹ Abbreviations used in this table:
A, Aneurysmorrhaphy or aneurysmotomy with intrasaccular ligation or transfixing of artery.
E, Excision.
² Operation performed overseas.

TABLE 47. SYMPATHECTOMY PERFORMED AFTER OPERATION FOR ANEURYSM AND ARTERIOVENOUS FISTULA

[Miscellaneous Indications]¹

Case No.	Location of lesion	Interval between injury and operation	Interval between operation and sympathectomy	Type of operation	Comment	Results
<i>Cases of Arterial Aneurysms</i>						
105	Brachial.....	Months 1.5.....	Months 3.0.....	² E	Complete paralysis upper extremity after injury, after several months gauntlet type anesthesia, etc., suggested residual paralysis was largely ischemic; hand cold, cyanotic.	Marked improvement began after sympathectomy; steady, significant but incomplete return of function.
106	Axillary.....	2.5.....	Same day	² E	Obviously impending gangrene of hand, especially of thumb, with marked ischemic paralysis following operation; also had traumatic plexus injury treated by alcohol injection.	Gangrene limited to thumb which was amputated; slow, steady, but incomplete recovery from ischemic and traumatic paralysis.
107	Femoral.....	3.0.....	One day..	² A	Foot extremely cold and pale after operation.	Excellent, good color and warmth.
108	Brachial.....	1.0.....	12.0.....	² E	Causalgia, severe C. S., severe plexus injury including irreparable damage to musculocutaneous nerve.	Causalgia relieved; cold sensitivity lessened, nerve return satisfactory.
109	Popliteal.....	0.5.....	1.0.....	² E	Causalgia and peroneal paralysis followed operation.	Causalgia greatly relieved.
110	Profunda femoris.	2.0.....	1 week....	E	Moderate causalgia temporarily relieved by sympathetic block; tibial palsy, definite hypochondriasis.	Immediate relief slight, subsequent complete relief with exercise and encouragement.
<i>Cases of Arteriovenous Fistulas</i>						
111	Femoral.....	2.0.....	3.0.....	² Trans-saccular ligation.	Stocking hypesthesia up to just below knee, foot largely anesthetic; extensor paralysis toes 1 and 2, ischemic palsy following operation.	No anesthesia, hypesthesia only of foot, regained extension of toes; improvement began few days after sympathectomy.
112	Femoral.....	1 week.....	3.5.....	² E	Boot anesthesia and complete tibial and peroneal paralysis followed operation, regained tibial function promptly; on admittance peroneal motor loss complete, sensory almost complete.	Improvement began within a few days, complete recovery.
113	External iliac.	1.5.....	3.5.....	² E	Some C. S., poor collateral circulation; a second (hypogastric) A-V fistula remained to be excised.	Excellent, good circulation following excision of hypergastric fistula; no C. S.

See footnotes at end of table.

TABLE 47. SYMPATHECTOMY PERFORMED AFTER OPERATION FOR ANEURYSM AND ARTERIOVENOUS FISTULA—Continued

[Miscellaneous Indications]¹—Continued

Case No.	Location of lesion	Interval between injury and operation	Interval between operation and sympathectomy	Type of operation	Comment	Results
<i>Cases of Arteriovenous Fistulas—Continued</i>						
114	Cirroid of foot.	Months Unknown	Months 3.0-----	² E	Hyperhidrosis and cyanosis followed excision posterior tibial A-V; peroneal and anterior tibial A-V fistulas remained to be excised.	Foot remained warm, dry, and well colored after remaining fistulas were excised.
115	Femoral-----	8.5-----	1 week----	E	Foot had excellent circulation until 6th postoperative day when arterial and venous thrombosis occurred with coldness, numbness, and paresis of foot.	Some improvement with descent of cold level; gangrene of toes and sole of foot occurred, however.

¹ Abbreviations used in this table:
E, Excision.
A, Aneurysmorrhaphy or aneurysmotomy with intrasaccular ligation or transfixing of the artery.
C. S., Cold sensitivity.
² Operation performed overseas.

The third patient with ischemic paralysis (Case 105) had paralysis of the upper extremity after injury. When examined at the Mayo General Hospital, 3 months after excision of a brachial aneurysm and 4.5 months after injury, the gauntlet type of anesthesia and other findings made it evident that his residual paralysis was largely ischemic in character. The hand was cold and cyanotic and he complained of aching upon exposure to cold. Improvement was noted shortly after sympathectomy. The anesthesia receded steadily and 9 months later sensation in the extremity was normal except for hypesthesia of the dorsum of the hand and anesthesia of the palmar surface of the fingers. The hand was warmer and of good color and withstood exposure to cold fairly well. Return of motor function, although considerable, was still incomplete.

Two patients in the miscellaneous group (Cases 113 and 114) had multiple arteriovenous fistulas. In one (Case 113) there was some sensitivity to cold and evidence of extremely poor collateral circulation following excision of an external iliac fistula. The operation had been performed overseas. When the patient was admitted to Mayo General Hospital a second fistula remained to be excised. At operation this was found to involve the neighboring hypogastric vessels. Sympathectomy was performed and immediately afterward tests of the collateral circulation showed it to be adequate. This fistula was therefore excised. Thereafter, circulation in this limb was excellent. The second patient (Case 114) had a congenital cirroid aneurysm of the foot with

distinct individual fistulas of the anterior and posterior tibial and peroneal vessels. Excision of the posterior tibial fistula was followed by extreme hyperhidrosis and cyanosis of the foot which persisted for several months. Sympathectomy was performed and thereafter the foot remained warm and dry. The remaining fistulas were resected without difficulty.

Sympathetic interruption was carried out in 2 patients (Cases 106 and 115) because of obviously impending gangrene. One of these patients (Case 106) had been operated upon overseas nearly 3 months after an injury which had produced partial paralysis of the brachial plexus. An aneurysm of the axillary artery was encountered unexpectedly at operation and excised. After operation the hand became cold and cyanotic, and the thumb, in particular, seemed devoid of circulation. Alcohol injection of the dorsal sympathetics was accomplished successfully, but gangrene of the thumb occurred and required amputation. Fairly good circulation was restored in the remainder of the hand. In this patient definite ischemic paralysis had been superimposed on the pre-existing damage to the brachial plexus. Steady improvement in nerve function occurred, but recovery was incomplete. The second patient (Case 115), who at first had had good warmth and color in the foot after excision of a femoral arteriovenous fistula, on the sixth postoperative day suddenly complained of pain and swelling in the foot and leg with coldness, numbness, and paresis of the foot. It was apparent that extensive arterial and venous thrombosis had occurred. Although spinal analgesia produced little improvement in the circulation, sympathectomy was performed because the situation was desperate. The cold level became lower and circulation improved but the improvement was insufficient to prevent gangrene of the toes and sole of the foot, and amputation was required.

In another patient (Case 107) sympathectomy was performed the day after aneurysmorrhaphy because the foot became alarmingly cold and pale. In this patient the foot regained good warmth and color promptly.

Sympathectomy was carried out in 3 patients (Cases 108, 109, and 110) because of causalgia. All 3 had suffered peripheral nerve damage and 1 had severe sensitivity to cold. In each, temporary relief followed a series of sympathetic blocks, but lasting effect was not achieved. After sympathectomy causalgia was promptly and completely relieved in 1 patient and greatly relieved in another. The third patient continued to complain of pain after operation. He had, in addition, other complaints which suggested hypochondriasis. Under reassurance and exercise the pain of which he complained finally disappeared.

COMMENT

If patients who have circulatory difficulties following the operative cure of peripheral aneurysms or arteriovenous fistulas are to be provided with the best possible limbs, and if the desire is not merely to avoid such gross ischemic disasters as gangrene, repeated investigation of the circulatory status

of the affected limbs is necessary. Just the casual observation of patients on a ward will not reveal the true circulatory status of their injured extremities. It is important to test these affected limbs in order to ascertain whether exercise can be tolerated without crippling pain, to make certain that no distressing symptoms ensue when they are exposed to cold, to see that persistent edema or ischemic paralysis is not present, and to make sure that return of nerve function in instances of associated peripheral nerve injury is not being compromised by inadequate circulation. The experience at this center during World War II shows that in certain instances the performance of sympathectomy will correct these circulatory difficulties.

Special Effects of Sympathectomy

Exercise Tolerance. As was noted in the discussion of preoperative sympathectomy, fatigue on exercise occurs in a striking fashion in the lower extremity after ligation of the iliac, femoral, or popliteal artery and in a less notable degree in the upper extremity after ligation of the subclavian, axillary, or brachial artery. Exercise tolerance of the lower extremities was determined in the patients upon whom sympathectomy had been performed postoperatively, by measuring the number of yards they could walk at a normal pace before they were compelled to stop because of fatigue, or, less commonly, because of cramps in the calf. Exercise tolerance of the upper extremity was measured by having the patient squeeze once every second a rubber bulb which was connected to a 5-gallon bottle with a mercury manometer. The number of squeezing movements which the patients could perform before fatigue prevented further effort was recorded, as was the height of the manometer at the end of the test.

Statistically significant comparisons were not possible because these studies were carried out both before and after sympathectomy on only a small number of patients. Many patients were not tested because of associated fractures or motor paralysis. Results of the test showed, however, that patients upon whom sympathectomy had been performed after ligation of the femoral or popliteal artery experienced fatigue or cramps after walking an average of 0.82 mile; approximately the same distance walked by patients with similar lesions treated by ligation but without sympathectomy (see Part I). Many patients showed no or only slight improvement in exercise tolerance after sympathectomy. On the other hand, a striking increase in exercise tolerance was occasionally observed. One patient (Case 84, Table 44), who was admitted 4.5 months after excision of a femoral aneurysm, could walk no more than half a mile because of aching and fatigue in the calf. Within 2 weeks after sympathectomy had been performed on the indication of sensitivity of the foot to cold, he could walk 2 miles before experiencing fatigue in the calf. Improvement of such a degree was, however, exceptional.

Cold Sensitivity. Next to diminished ability to exercise the limb without fatigue, the commonest postoperative circulatory difficulty is cold sensitivity.

If, as has already been pointed out, it is of mild degree, or if it occurs in patients who live in warm climates, it is not likely to cause real discomfort or disability. When it exists in rather severe degree or is present in patients whose place of residence and type of work require exposure to low temperatures, the symptoms are distressing and often disabling.

As the patients in this series show, sympathectomy which was performed on this indication yielded excellent results. Sympathetic blocks with procaine followed by exposure to cold served as excellent guides as to what might be expected of sympathectomy.

Persistent Edema. Persistent edema of significant degree is unusual after operation for aneurysms or arteriovenous fistulas. If it occurs it should be treated by rest, elevation of the limb, elastic support, and graduated activity with the limb dependent for a sufficiently long period of time. If these measures prove ineffectual after a fair trial, sympathetic blocks or sympathectomy may be of real value.

It was noted that if they caused transient though not permanent diminution in swelling, sympathectomy was likely to be very helpful, but even if no effect upon the edema was noted after the blocks, sympathectomy was occasionally effective. Certainly sympathectomy was of real value in every instance when it was performed on this indication in this series—even if the prospects indicated by sympathetic block had been poor.

Ischemic Difficulties. When ischemic difficulties are present, the efficacy of sympathectomy depends upon the capacity of the collateral circulation to improve through the elimination of persistent or intermittent vasoconstriction and the maintenance of a state of vasodilatation. As with other disorders in which the arterial blood flow has been interrupted, this capacity varies in different individuals.

In the Mayo General Hospital experience, sympathectomy was strikingly successful in ischemic nerve paralysis. The results in the two patients in whom gangrene was imminent were less striking. Nonetheless, the procedure should be given consideration in such patients even if the limb shows only slight improvement with sympathetic block or spinal analgesia. In occasional instances of impending or spreading gangrene caused by occlusion of arteries from other causes, sympathectomy has produced striking benefits even after a poor response to preliminary tests.

The experience at this center also suggested that sympathectomy was indicated in patients in whom severe nerve damage was associated with obviously impaired circulation. The evidence of good return of nerve function in these patients would seem to justify the procedure. Unfortunately, there were available no carefully controlled clinical studies comparing nerve regeneration in patients in whom sympathetic interruption had been carried out with those in whom it had not been carried out. Furthermore, sympathetic procaine block did not invariably furnish reliable information concerning the results to be expected following sympathectomy.

It was noted at this center that if the nerve paralysis had not produced sensory loss in the entire hand or foot, improvement in the circulation produced by sympathetic procaine block could be readily demonstrated by skin temperature changes in the normally innervated digits. If, on the other hand, normal sensation and intact sympathetic innervation had been lost in all parts of the hand or foot, ordinarily no rise in skin temperature could be demonstrated during the block. That sympathectomy may actually increase the circulation in these patients was suggested by a number of phenomena, namely, the decreased tendency to dependent cyanosis which was sometimes noted after operation, diminution in sensitivity to cold, an occasional increase in circulation as demonstrated by the oscillometer and, in particular, the striking improvement in nerve function which so often followed if part of the neurologic damage was ischemic in character. Sympathectomy naturally did not alter the tonus of blood vessels if there was anesthesia of portions of the skin and consequently local sympathetic denervation. It was equally apparent, however, that blood flow in the limb was increased by the elimination of vasoconstriction from the vessels of the limb as a whole.

Factors Influencing the Development of Postoperative Circulatory Difficulties

A comparison of the patients operated on overseas and those treated at the Mayo General Hospital reveals certain profitable data concerning factors influencing the occurrence of postoperative difficulties for which sympathectomy is required. If only those patients are considered in whom the main arteries to the extremities were involved (innominate, subclavian, axillary, brachial, external iliac, common femoral, and popliteal arteries), 17 of 42 patients in the overseas group were treated by sympathectomy (40.5 percent) against 17 of 182 patients in the Mayo General Hospital group (9.3 percent). If those patients upon whom sympathectomy was carried out before or at the time of operation are eliminated, likewise those in whom the continuity of blood flow through the affected artery was successfully maintained, the figures for the overseas group become 17 of 41 cases (41.5 percent) and for the Mayo General Hospital group 17 of 108 cases (15.7 percent). Sympathectomy was performed upon 1 patient in each group for the additional reason that a second arterio-venous fistula required excision.

In general, the time interval between injury and operation for the vascular lesion was shorter in the overseas group than in the Mayo General Hospital group. In the former it ranged from a few days to 4.5 months and averaged about 1½ months. In only about 17 percent of the patients was the interval 3 months or longer. In the Mayo General Hospital group, exclusive of 1 patient with a lesion of 13 years duration, the interval ranged from 6 weeks to 15 months and averaged about 5 months. In about 85 percent of those in this group the interval was 3 months or longer.

Unfortunately, the overseas group and the Mayo General Hospital group are not entirely comparable. Early operation was apparently forced by com-

plicating circumstances in a somewhat higher percentage of the patients operated on overseas than in those treated at the Mayo General Hospital. There were also other differences. Often patients in the overseas group were operated upon by a number of surgeons whose experience in vascular surgery was limited; whereas those in the Mayo General Hospital group were treated by a few surgeons who were specialists in the field of vascular disorders. Careful testing of the collateral circulation before operation was routine at the Mayo General Hospital. If the clinical case records are taken at their face value and if the replies of patients to questioning can be accepted, these tests were carried out only rarely in patients operated upon overseas. The two groups are therefore not comparable because of these extremely important factors. Nevertheless, it may be concluded from the data available that postoperative circulatory disorders follow more frequently operations performed upon aneurysms and fistulas of relatively short duration. This hypothesis can probably be expressed more accurately by stating that the incidence of postoperative difficulties is less when an adequate collateral circulation is established before surgery is undertaken. It must be emphasized that although the collateral circulation tends to be better when the lesion has been in existence a long time, especially in patients with arteriovenous fistulas, there are frequent exceptions to the rule, and careful testing is mandatory.

CHAPTER XII

Arterial Aneurysms and Arteriovenous Fistulas Spontaneous Cures

Harris B. Shumacker, Jr., M. D.

For many years spontaneous cures of both arterial aneurysms and arteriovenous fistulas have been recorded in the medical literature. These accounts have appeared chiefly in the form of isolated case reports or as single examples in small series of cases. By 1907, according to Matas,¹ Boinet was able to collect 60 such cures in aortic aneurysms alone. Spontaneous cures of arteriovenous fistulas have been reported less frequently than cures of arterial aneurysms. The cures of aneurysms have included both saccular and fusiform types and the lesions have occurred in practically all arteries. The duration of the lesion before cure occurred has varied from a few months to many years.

Because of the character of the reports in the literature, it is almost impossible to determine anything concerning the frequency with which spontaneous cures occur. Winslow² found only 1 instance of spontaneous cure in 86 aneurysms of the internal carotid artery and none in 19 arteriovenous fistulas, while Callander³ mentioned only 1 instance of cure among the 447 arteriovenous fistulas which he analyzed. A few other cases are described in which the lesion disappeared after treatment by compression.

The literature thus supplies little information concerning the frequency of spontaneous cures of arterial aneurysm and arteriovenous fistulas, the adequacy and permanency of these cures, and the therapeutic means by which they can be encouraged to take place.

Among the 119 aneurysms and 245 arteriovenous fistulas observed at the vascular center of Mayo General Hospital, there were 8 spontaneous cures of arterial aneurysms and 5 of arteriovenous fistulas. Two additional aneurysms became solidly clotted but had to be excised because of associated nerve lesions, and 3 additional arteriovenous fistulas underwent spontaneous cure by thrombosis of the affected vein, but persistence of associated saccular aneurysms made surgery necessary in each of these cases. With 11 exceptions, 7 of which were of congenital origin, these 364 lesions were traumatic.

¹ Matas, R.: Surgery of the vascular system. In Keen, William W., and DaCosta, John C.: *Surgery: Its Principles and Practice*. Philadelphia, W. B. Saunders Co., 1909, vol 5, pp. 17-350.

² Winslow, N.: Extracranial aneurysm of the internal carotid artery; history and analysis of the cases registered up to August 1, 1925. *Arch. Surg.* 13: 689-729, Nov 1926.

³ Callander, L.: Study of arteriovenous fistula with an analysis of 447 cases. *Johns Hopkins Hosp. Rep.* 19: 347-362, 1921.

It was possible to determine from notes made at the time of operation and from examination of excised specimens, the types of fistulas and the presence or absence of associated saccular aneurysms in 195 arteriovenous fistulas observed at Mayo General Hospital during the course of World War II. In 78, 40 percent, no aneurysm was present; there was only a direct communication between artery and vein. In the other 117, 60 percent, one or more aneurysms were present, and these varied in size from a mass 1 cm. in diameter to an ovoid mass about 22 cm. long and 15 cm. in diameter.

SPONTANEOUS CURES OF ANEURYSMS

Analysis of Data

Of the 119 aneurysms observed at the vascular center of Mayo General Hospital in the course of World War II spontaneous clinical cure occurred in 10 instances. In 8 of these (6.7 percent of the total number) the end results were satisfactory without local treatment in that the mass disappeared. In the other 2, the thrombosed sac persisted and required surgical treatment because of associated nerve lesions, in 1 of these because of pressure of the thrombosed mass on the nerve rather than because of trauma to the nerve per se. In 3 of the 10, the aneurysms arose from relatively small arteries as, for example, the posterior tibial and the ulnar. In the 7 remaining, larger arteries such as the carotid, brachial, femoral, popliteal, and axillary were involved.

In the 10 patients in whom thrombosis occurred, the process began from 1.5 to 4.5 months following injury and was complete in from 2 to 15 months. These time intervals are to be compared with approximately 3.5 months, the average duration of the lesion at the time of operation in the 109 aneurysms in the series treated by surgical measures.

In 6 of the 10 patients the thrombosis seemed to occur rather suddenly and to be complete immediately. In the other 4, it was a gradual and progressive process. In general, a marked contraction of the clotted sac took place, and in the 8 patients in whom cure was entirely satisfactory the mass either disappeared completely or became insignificant in size. One patient (Case 5) had had sympathectomy performed on the indication of poor collateral circulation prior to the time the thrombotic process began, and in another patient (Case 2) a traumatic sympathetic denervation had resulted from the same injury which produced the vascular lesion.

Brief abstracts of the 10 cases in which aneurysms cured spontaneously are presented herewith:

Case 1. A 27-year-old soldier received multiple penetrating wounds from fragments of an exploding shell. Thereafter there were present signs and symptoms of an aneurysm of the left common carotid artery including paralysis of the left vocal cord, vigorous pulsation of a palpable mass, a systolic bruit, and the subjective sensation of a short, swishing sound heard synchronously with each heart beat. In a hospital overseas an exploratory operation was carried out 1 month after injury but no attempt was made to correct the vascular lesion.

Some 3 months later, while the patient was being evacuated by sea to the Zone of Interior, he observed that the swishing note had disappeared and that the mass was pulsating less forcefully. When examined a few weeks later in the vascular center of Mayo General Hospital a firm pulsating mass about 2 cm. in diameter was palpable in the region of the left common carotid artery. Proximal compression of the artery temporarily stilled the pulsation of the mass. Four months later (8 months after injury) examination revealed practically the same findings. At the end of another 4 months the mass was no longer palpable and there was no evidence of the thrill, bruit, or abnormal pulsation previously present. The left common carotid artery pulsated normally proximally and distally to the site of the original mass. It was concluded that the aneurysm had cured spontaneously and that the lumen of the artery had been preserved.

The first improvement was observed during the time the patient was at sea, but he had not been seasick and dehydration could not be regarded as initiating the chain of events leading to cure (see Case 18).

Case 2. A 25-year-old soldier was injured by a shell fragment 7 weeks before he was seen at this vascular center in the Zone of Interior. He had a pulsating mass about 3.5 by 5 cm. in the left side of the neck (Figs. 46A and B). The mass was compressible and was associated with a loud systolic bruit. It ceased to pulsate when the left common carotid artery was occluded proximally. There was also evidence of left cervical sympathetic and of left recurrent laryngeal paralysis.



Figure 46. (Case 2.) A and B. Aneurysm of left carotid artery 8 weeks after injury. C Five months later after apparent spontaneous cure of lesion. Note normal contour of the neck. (See p. 362.) It is unfortunate that no postoperative photograph was made in precisely the same position as one or the other of the preoperative photographs. The presence of normal skin creases, however, and the clear anterior margin of the sternomastoid muscle, show reasonably well the absence of any visible mass.

The soldier was granted a furlough and after his return an examination revealed that the mass was smaller, firmer, and pulsated less vigorously. In addition, the bruit had disappeared. At this time 4 months had elapsed since the date of injury. The mass continued to decrease rapidly in size and 6 weeks later it was only a firm, nonexpansible nodule about 1.5 by 0.7 cm. in size adherent to the carotid artery. Two months later (7½ months after injury), examination revealed the same findings. (Fig. 46C.) No signs of aneurysm were present and the carotid artery pulsated normally proximally and distally.

Case 3. A 30-year-old soldier was wounded by machinegun fire. A small arterial aneurysm of the midportion of the brachial artery developed, also paralysis of the right median nerve. The aneurysm measured about 2 by 1.5 centimeters. Examination revealed expansile pulsation of the mass and a systolic bruit.

Six weeks after injury the mass became firmer and ceased to expand with pulsation. The changes were associated with definite local pain and tenderness. The mass continued to decrease in size and after several months had elapsed was no longer even palpable. The hand, however, showed evidence of persistent vasospasm and was sensitive to cold.

Seven months after injury, during operative neurolysis of the median nerve, it was possible to inspect the brachial vessels. Both the artery and the vein were thrombosed and were excised. A study of the specimen revealed a defect in the arterial wall which represented the former mouth of the aneurysm. No sac could be found. Return of median nerve function was satisfactory but sensitivity to cold continued and a dorsal sympathectomy was therefore carried out. The results were excellent.

Case 4. A 23-year-old soldier was injured by the explosion of a land mine. He sustained fractures of the right radius and ulna and of the left femur, laceration of the mesentery of the ileum for which laparotomy was performed, and an injury to the right common femoral artery. When examined at the vascular center of Mayo General Hospital 6 weeks later, a pulsating mass about 3 cm. in diameter was found in the right groin over the junction of the external iliac and common femoral arteries. A systolic thrill and a bruit were present. Direct pressure over the mass or over the distal portion of the external iliac artery stilled the aneurysm.

Three months later the mass was smaller and firmer. It still expanded with pulsation and the bruit was still present but the thrill had disappeared. Examination a year after the injury showed that the original pulsating mass had been replaced by one that was small and indurated. This mass completely disappeared 3 months later. There was no other evidence of the presence of an aneurysm at either of these examinations.

Case 5. A 24-year-old soldier was injured by a shell fragment. When examined 2 months later a compressible dumbbell-shaped mass 6 cm. in diameter was present over the upper portion of the left femoral artery. Expansile pulsation was palpable and a systolic bruit heard. Both pulsation and bruit were abolished by compression of the common femoral artery. Tests revealed the collateral circulation to be inadequate and left lumbar sympathectomy was performed. The circulation was improved after this procedure but was still regarded as inadequate.

Two months later, while the patient was on furlough, the mass became firm and ceased to pulsate. Examination on his return a few weeks later showed that the 6-cm. pulsating mass had been replaced by a hard, nonexpansile mass 2 cm. in diameter and without any associated thrill or bruit. The mass continued to decrease in size and 9 months after the original injury an arteriogram revealed a sac only about 0.5 cm. in diameter. At the end of another month the mass was still smaller; only a tiny, firm nodule was palpable. Oscillographic readings showed that the circulation was normal in the thigh, calf, and ankle on the affected side. Appropriate tests showed that the patency of the artery had been maintained.

Case 6. A 26-year-old soldier was injured in the right popliteal area by a shell fragment. Soon afterward a pulsating mass developed in this area associated with a systolic bruit. About 6 weeks after injury the mass became smaller and firmer and ceased to pulsate. At the end of another 2 weeks it had disappeared entirely as had the bruit. The popliteal artery and its anterior and posterior tibial branches all pulsated normally.

Case 7. A 32-year-old soldier was injured by a shell fragment. Soon afterward a pulsating expansile mass appeared on the posteromedial aspect of the leg just above the internal malleolus. A diagnosis of a posterior tibial aneurysm was made. Two months after injury the pulsating mass became firm and did not pulsate. Examination revealed a solid mass about 1.5 cm. in diameter. No bruit or thrill was present. No posterior tibial pulse could be palpated distal to the mass. Examination 2 months later showed little change in the mass, but at the end of another 4 months it was neither visible nor palpable. The posterior tibial pulse distal to the site of injury was still absent.

Case 8. A 26-year-old soldier received multiple penetrating wounds from shell fragments. A small pulsating mass, associated with a loud systolic murmur, developed in the middle third of the right calf. It was diagnosed as a posterior tibial aneurysm. During the third month after injury, while the patient was on furlough, the mass ceased to pulsate and became firm and indurated. Examination revealed neither thrill nor bruit. The induration gradually subsided. An arteriogram 4 months after injury revealed a normal-appearing arterial tree. There was no suggestion of aneurysmal dilatation at the site of injury but in the roentgenogram the site of the injury was marked by the presence of a small shell fragment.

Case 9. A 23-year-old soldier was wounded in the right axilla by shell fragments. At the time of wounding there was considerable bleeding. No numbness or paralysis was noted. A pulsating mass soon developed in the axilla and a systolic bruit became audible. Six weeks after injury some loss of sensation was noted in the digits and a week later the extensor power of the wrist and forearm was lost and all movements of the hand became weak. These neurologic changes persisted.

When the patient was examined at this vascular center some 5 months later he stated that pulsation in the mass had recently ceased. Examination showed a solidly thrombosed aneurysm in the right axilla (Fig. 47). The brachial, radial, and ulnar pulses were absent. Complete radial and partial ulnar and median paralysis was present, and the sequence of events left no doubt that nerve damage had resulted from pressure from the axillary aneurysm.



Figure 47. (Case 9.) Right axillary aneurysm 3 months after injury.

An exploratory operation was performed and an axillary aneurysm was found which measured between 5 and 6 cm. in diameter. The axillary artery was thrombosed distal to the lesion. The median, ulnar, and radial nerves lay in grooves in the wall of the aneurysmal sac (Fig. 48). The median nerve showed only a little damage and the ulnar nerve was only moderately thinned, but the radial nerve was thinned out to a fine thread for a distance of 3.5 cm.; strong faradic stimulation in this area yielded no response. The aneurysm was excised after which the damaged portion of the radial nerve was resected and the ends sutured. The postoperative course was smooth.

When the excised aneurysm was opened it was found to be completely filled with thrombus, most of the clot was old and well organized. Near the mouth of the sac, however, was a small portion which was fresher and less well organized.

Case 10. A 20-year-old soldier sustained a wound from a rifle bullet in his left hand. An ulnar aneurysm developed in the hypothenar space and there was some damage to the digital nerves. By the end of the third month after injury the aneurysm was completely thrombosed, but over the next 7 weeks it did not decrease in size and there was no improve-

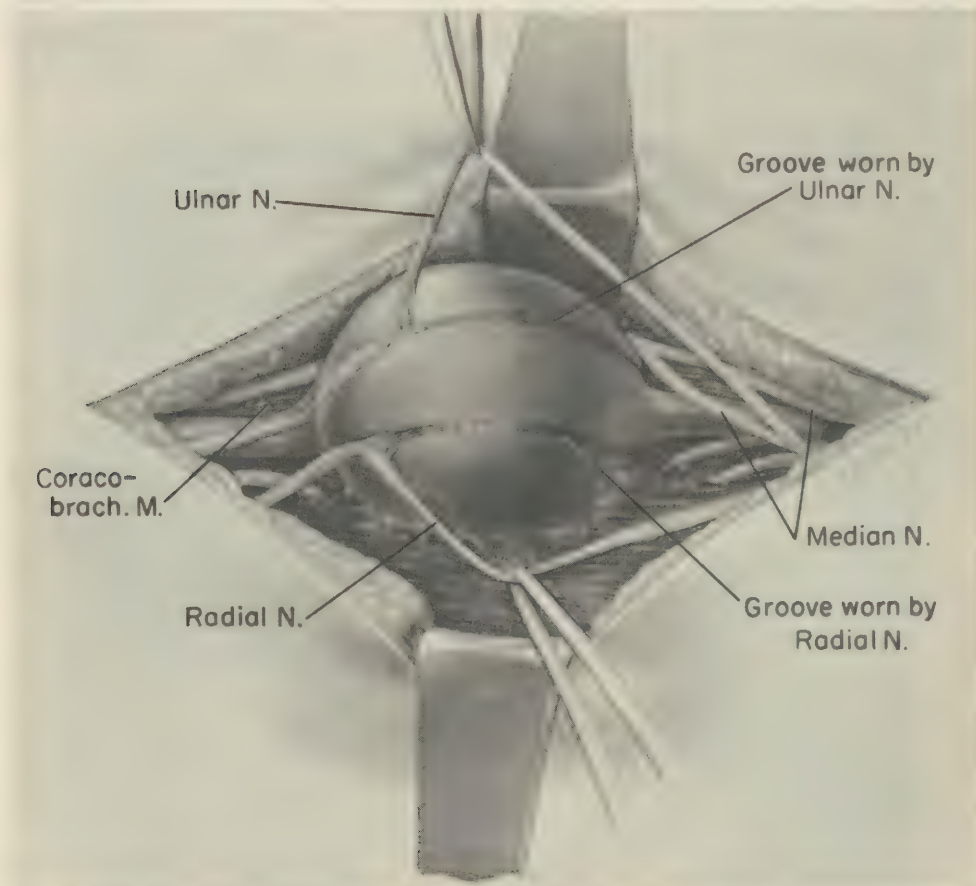


Figure 48. (Case 9.) Drawing of conditions found at operation. Note relationship of nerves to lesion.

ment in the neurologic condition. Operation was therefore performed. The aneurysm, which was 1.5 cm. in diameter, was solidly clotted and the artery distal to it, thrombosed. The sac was evacuated and the injured nerves sutured. Recovery was uncomplicated.

SPONTANEOUS CURES OF ARTERIOVENOUS FISTULAS

Analysis of Data

Of the 245 arteriovenous fistulas observed at this vascular center during World War II, apparently spontaneous clinical cure occurred in 8 instances. In 5 (2 percent of the total number) the end results were satisfactory without further local treatment. A saccular aneurysm was known to be associated with the fistula in 2 of the 5. In the other 3, while the fistula was closed by spontaneous thrombosis of the vein, an associated saccular aneurysm persisted and operation was necessary. In all but 1 or 2 the artery involved was a large vessel such as the carotid, brachial, subclavian, or femoral.

In the 5 patients in whom the end result of spontaneous cure was entirely satisfactory, the process of obliteration began 1.5 and 5.5 months after onset of the lesion. In 4 of these patients the process began within 3 months or less. In all 4 the process occurred rather suddenly, leading one to infer that closure of the fistula was achieved by thrombosis rather than by scarring and fibrosis which is a more gradual process. In the remaining patient in this group the process occurred gradually, beginning within 2 months after injury and completed within the next 1.5 months.

In only 2 instances was the presumption concerning the method of cure established: In 1 instance (Case 11) by the presence of a palpable, thrombosed saccular aneurysm, and in the other (Case 12) by clinical observation of thrombosis of the vein, confirmed by later inspection of the involved vessels at operation. In the 3 patients in whom operation was necessary because of persistence of an associated aneurysm, the process of obliteration began, respectively 1.5, 3.9, and 4 months after injury. The time intervals in this group and in the preceding group of patients in whom completely successful spontaneous cure occurred should be compared with 5 months, the average interval between injury and operation in the 237 arteriovenous fistulas treated by surgical excision.

Another point of interest is the proportion of patients in whom cure occurred as the result of thrombosis. This is in contrast to the general experience that experimentally produced arteriovenous fistulas often close, when they do so spontaneously, by gradual scarring and contraction of the communication rather than by thrombosis.

One of the patients who had a completely satisfactory spontaneous cure, and 2 of the 3 who required further surgery, had undergone sympathectomy before the fistula became obliterated. In 1 of these patients (Case 18) thrombosis of the vein was obviously associated with dehydration and shock.

Brief abstracts of the 8 cases in which spontaneous cures of arteriovenous fistulas occurred are presented herewith:

Case 11. A 34-year-old soldier received multiple penetrating wounds from a land mine explosion. He developed 2 arteriovenous fistulas, 1 involving the right common carotid artery and internal jugular vein, 1 the right femoral artery and vein. The femoral fistula was excised about a month after injury. Two months later the buzzing sensation, which had been present in the right side of the neck since the arteriovenous fistula had developed, suddenly ceased. Examination revealed that the previously continuous thrill had disappeared while of the continuous bruit formerly present only a slight systolic component now remained. A rubbery, nonexpansile mass had replaced the original carotid aneurysm. The carotid artery pulsed normally both proximally and distally to the lesion. Within another month the systolic bruit disappeared, and the mass became progressively smaller so that by 6 months after injury it was barely palpable.

Case 12. A 22-year-old soldier sustained a shell-fragment injury. A brachial arteriovenous fistula associated with a small saccular aneurysm developed, also a partial median paralysis. He was admitted to this vascular center 6 months after injury. A continuous thrill and bruit were present, and compression of the fistula resulted in bradycardia. Seven weeks after injury thrombosis of the dilated brachial vein became evident and signs of the arteriovenous fistula disappeared. Since steady improvement was apparent in median nerve function, operation was deferred. After the lapse of about 4½ months there was complete recovery of motor function, but anesthesia of the median nerve distribution persisted. A neurolysis was carried out. At this time the brachial artery and vein were inspected and were found completely thrombosed, adherent to each other. A tiny, solid mass was all that remained of the original saccular aneurysm.

Case 13. In a 26-year-old soldier an arteriovenous fistula of the femoral vessels developed in the midportion of the thigh following a wound from a rifle bullet. Two months after injury the continuous bruit and thrill which had been present since the fistula developed became much less prominent. A month later the thrill was barely palpable and the bruit, though still continuous, was very faint. Pulsations were good in the popliteal, dorsalis pedis, and posterior tibial arteries. Within the next 2 weeks all signs of the fistula disappeared and they did not reappear during an additional month of observation. Whether the lesion in this patient involved the femoral vessels or some of the smaller branches was not definitely established.

Case 14. A 25-year-old soldier was injured by a shell fragment. One month later clear-cut signs of an arteriovenous fistula in the left thigh below the inguinal region were present. These persisted for 2 months, then disappeared. When the patient was examined 4 months after injury no abnormal pulsation was present, no thrill could be palpated, and no bruit heard.

The notes were not sufficiently complete to permit accurate localization of the fistula, but the findings suggested that it involved branches of the profunda femoris vessels. The continuous bruit and thrill noted by several competent observers before the patient was seen in this vascular center left no doubt that an arteriovenous fistula had actually been present.

Case 15. A 24-year-old soldier received a penetrating shell-fragment wound of the left chest wall. There was transient paralysis of the left upper extremity and some numbness which did not subside for several weeks. Soon after injury signs suggestive of a subclavian arteriovenous fistula appeared. When he was examined about 2½ months after injury, a strong and continuous thrill was palpable just above the inner third of the clavicle. An extremely loud and continuous bruit was transmitted into the mediastinum, up into the neck, and down the arm to the midforearm. The subclavian vessels could not be occluded by digital pressure nor could the thrill and bruit be eliminated. Minimal hyperesthesia was present in the ulnar distribution. A diagnosis of subclavian arteriovenous fistula was made.

Because of a rather striking vasoconstriction in the left upper extremity and the inability to occlude the subclavian artery for testing the collateral circulation, a dorsal sympathectomy was performed about 4½ months after injury. Some days later the thrill previously felt over the lesion disappeared and the continuous bruit was replaced by a loud, short, systolic bruit. The subclavian vessels were explored shortly afterward in the belief that though the fistula had been obliterated a saccular aneurysm remained. The vessels were traced proximally to the point at which they emerged from the mediastinum. There was considerable scarring in this area but no aneurysm could be palpated. Since the remaining bruit could be explained by compression of the artery by scar tissue, exploration was discontinued. The short systolic bruit persisted, but became less intense, during the 6-week period of observation after operation.

There was unmistakable evidence in this case of the presence of an arteriovenous fistula, and it seems likely that it involved the first portion of the subclavian vessels.

Case 16. A 24-year-old soldier was injured by fragments from a bazooka shell. Because of gas gangrene a right midthigh amputation was necessary. A large left femoral aneurysm developed. Three months after injury, examination revealed a very large pulsating mass in the left thigh, associated with a loud systolic bruit. The aneurysm could be stilled by proximal compression of the femoral artery. Testing showed the collateral circulation to be entirely inadequate. Left lumbar sympathectomy was performed and the circulation became satisfactory; aneurysmorrhaphy was carried out thereafter. The sac was huge and in addition to a large free cavity contained 2.5 liters of partially organized thrombus. The midportions of the femoral artery and vein each opened separately into the sac through large rents. In this area the femoral vein was completely occluded by a well-organized thrombus.

When this patient was first examined at the vascular center only an arterial aneurysm was present. The previous records also contained no description of findings diagnostic of an arteriovenous fistula. The findings at operation, however, left no doubt that the original lesion was an arteriovenous fistula and that the artery and vein had communicated via the large sac described. Thrombosis of the vein had converted the fistula into an arterial aneurysm.

Case 17. A 22-year-old soldier was struck in the left shoulder by a missile of unknown type. Immediately partial ulnar and radial paralysis developed. Two weeks later a small pulsating mass was noted in the upper portion of the left arm. Four days later the mass began to increase rapidly in size and the radial pulse disappeared. Ulnar and radial paralysis then became complete and a partial median paralysis developed. Causalgia which had appeared soon after the injury became much worse.

When the patient was examined at this vascular center 6 weeks after injury, a tense pulsating mass was found in the left upper arm and shoulder area associated with a continuous thrill and bruit. Sympathetic block produced transient relief of pain, and sympathectomy was performed. This produced permanent relief from most of the pain. Four days after operation the aneurysm again began to increase in size and simultaneously the continuous bruit and thrill disappeared; only a short systolic bruit remained.

When exploration was carried out the following day, the brachial artery and vein were found to communicate independently with a large, poorly organized sac. The vein was completely occluded by a thrombus recently formed.

Case 18. A 33-year-old soldier was injured by a machinegun bullet. Partial paralysis of the right ulnar and median nerves resulted. A brachial arteriovenous fistula and a small saccular aneurysm also developed. Three months after injury, since the collateral circulation appeared to be extremely poor, dorsal sympathectomy was performed. The collateral circulation showed gradual improvement and at the end of 5 weeks it was thought to be adequate for surgery.

At this time, before the operation could be performed, the patient had a severe attack of food poisoning with so much vomiting and diarrhea that a profound degree of circulatory collapse resulted. The epidemic was widespread and available fluids for intravenous use became depleted so rapidly that they were reserved for those in the severest states of dehydration and shock. This patient therefore did not receive adequate parenteral fluid until he was badly dehydrated and in such a state of collapse that his pulse was imperceptible. He recovered rapidly, however, after appropriate therapy.

The day after this episode it was observed that the continuous thrill and bruit previously associated with the brachial arteriovenous fistula had disappeared. The brachial pulse distal to the lesion was good. At exploration a few days later the brachial artery and vein were found to have communicated through independent openings into a saccular aneurysm about 2 cm. in diameter. The artery still opened freely into this sac but the vein had become thrombosed. The ulnar and median nerves were adherent to and stretched over the aneurysm. They were freed from the aneurysm and it was excised. Recovery was uneventful.

COMMENT

Incomplete notes unfortunately do not permit statistical statements concerning either the presence or the extent of intrasaccular thrombosis in the arterial aneurysms and arteriovenous fistulas observed at Mayo General Hospital. Certain general statements may, however, be made: Extensive intrasaccular thrombosis was the rule in large aneurysms with small mouths, and generally no thrombus was present in small aneurysms with relatively large openings into the parent artery. In some instances the thrombus was well organized and, ordinarily, the older the lesion the more complete was the process of organization. In some instances (Fig. 49) there was both a well-organized thrombus adherent to the wall of the sac, and a poorly organized red thrombus only loosely attached. In other instances only a poorly organized clot was present (Fig. 50). The size and extent of the thrombus varied widely. Several femoral aneurysms contained from 2 to 2.5 liters of recent and old clot. The progressive deposition of thrombus within the sac was often apparent clinically from the decrease in pulsation of the sac, a palpable increase in its firmness, and sometimes by a diminution in the thrill and bruit. Indeed, in one patient, a large aneurysm of the profunda femoris became so firm and so completely lost its pulsatile character and its bruit that, until arteriography revealed a persistent large cavity, it was thought to have undergone spontaneous cure.

It is a matter of considerable interest that in 6 of the 10 aneurysms in which spontaneous cures occurred, the continuity of the parent artery was preserved. In this connection, Ballance and Edmunds⁴ cited Scarpa, who wrote:

It is a certain and incontrovertible fact in practical surgery that a complete and radical cure of an aneurysm cannot be obtained in whatever part of the body this tumor is situated unless the ulcerated, lacerated, or wounded artery from which the aneurysm is derived is by the assistance of nature, or of nature combined with art, obliterated and converted into a perfectly solid ligamentous substance, for a certain space above and below the place of the ulceration, laceration, or wound.

⁴ Ballance, C. A., and Edmunds, W.: *A Treatise on the Ligation of the Great Arteries in Continuity with Observations on the Nature, Progress and Treatment of Aneurysms*. London, Macmillan and Co., 1891.

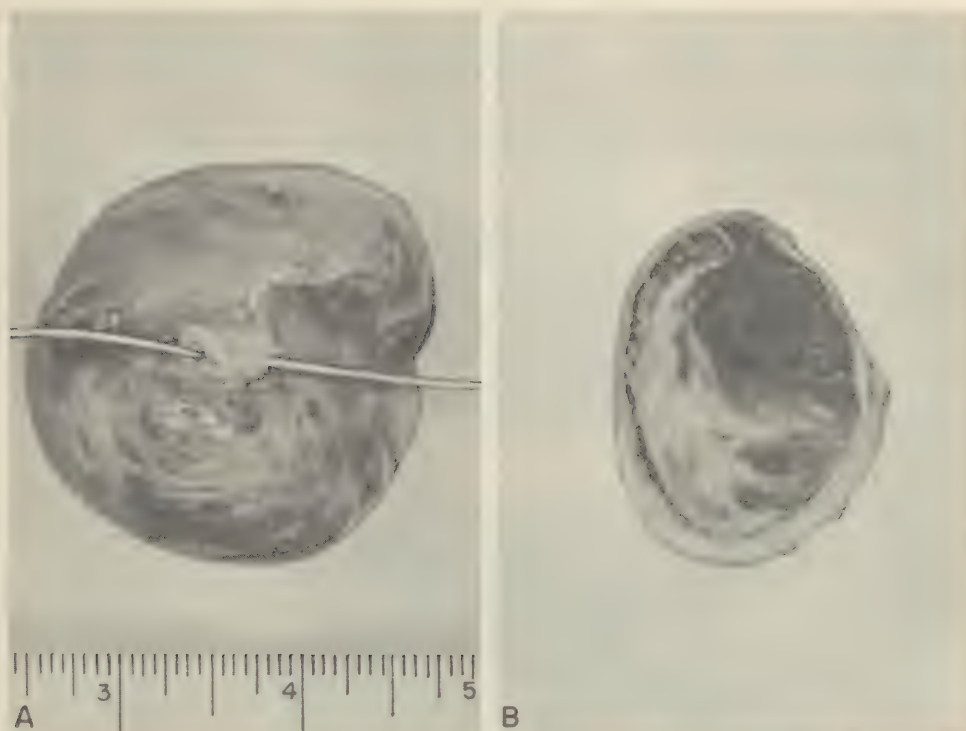


Figure 49. Traumatic aneurysm excised 11 years after its origin. A. Intact specimen. B. Transected specimen showing well-organized thrombus. Some poorly organized red thrombus can be seen along the margin of the cavity and between the organized thrombus and the sac wall in that area where the old thrombus is not fixed to the wall. The sac in this view is smaller because it has been fixed and shrunk in formalin solution.

This "truth," according to Ballance and Edmunds, writing in 1891, had never been disproved; they had been unable to find the record of a single cure which had occurred in any other way. The experience of the vascular center of Mayo General Hospital, however, indicates that apparently complete cures may occur with preservation of the artery.

In discussing the possible factors involved in the spontaneous cure of arterial aneurysms, Matas⁵ wrote as follows:

The conditions which provoke or favor this occurrence may be classified under three heads: (1) Those which favor clotting in the sac by retardation or arrest of the current through it; (2) those which increase the coagulability of the blood; (3) those which provoke coagulation through changes in or about the walls of the sac (Stimson). All these may be briefly summarized as follows: Spontaneous recovery takes place by (1) gradual deposit of fibrin from the blood in a laminated manner on the walls of the sac, so that the

⁵ See footnote 1, p. 361.

aneurysm is completely consolidated and subsequently, by condensation and shrinking, becomes converted into a small, nodular mass of fibrous tissue. The artery, under such circumstances, may remain pervious or become converted into a fibrous cord as far as the first collateral branch above and below the seat of the aneurysm. Such a favorable termination may be brought about by retardation of the blood-current induced by (a) the lowering of the heart's action; (b) the pressure of the aneurysm upon the artery above its opening into the sac; (c) partial blocking of the mouth of the sac with a piece of detached coagulum; (d) the impaction of a piece of clot in the artery below the mouth of the sac; (e) the pressure of another aneurysm or a tumor upon the artery above the sac or on the sac itself; (f) the aneurysm rupturing and the effused blood compressing the artery leading to the aneurysm. (2) By filling of the sac with recent ordinary coagulum as distinguished from the deposit of old-standing laminated fibrin. The coagulation of the blood in the sac may be brought about by: (a) the complete blocking of the mouth of the sac by a piece of detached clot; or (b) the complete plugging of the artery above and below the aneurysm. The clot may thus become organized and transformed into a fibrous cord. (3) The inflammation and sloughing of the sac and the plugging of the artery above and below the clot.

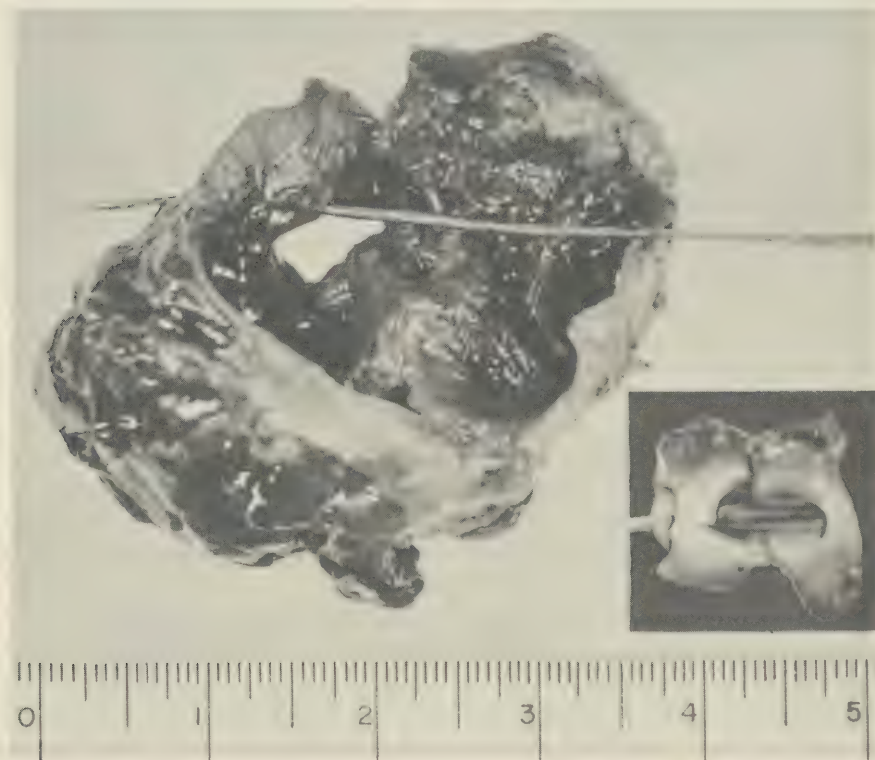


Figure 50. Poorly organized thrombus from a large brachial aneurysm of 2 months duration. Insert shows artery which has been removed from area of rectangular defect in the clot. The lesion in this case was an arteriovenous fistula; the artery and the vein communicated via a large sac into which each opened independently.

With a single exception, no factors were evident in these cases which could be singled out as possibly having contributed to the spontaneous cure either of arterial aneurysms or of arteriovenous fistulas. In this exceptional case (Case 18) a fistula was obliterated by thrombosis of the vein during a period of extreme dehydration and circulatory collapse due to fluid loss from diarrhea and vomiting. In some the process occurred while the patients were confined to bed; in none was there a coincident history of local trauma.

As already mentioned, in 1 patient in whom an arterial aneurysm underwent spontaneous cure, sympathectomy had been performed before the process of thrombosis began, while in another patient a traumatic sympathetic denervation had occurred. Sympathectomy had also been performed upon 1 patient with an arteriovenous fistula in whom an entirely satisfactory spontaneous cure occurred, and upon 3 other patients in whom a saccular aneurysm persisted.

Altogether, therefore, spontaneous cure occurred in 6 of 77 patients in whom sympathetic denervation had been produced by operation or trauma, and in 12 of 274 patients (presenting a total of 287 lesions) in whom sympathetic function of the part was intact. Clinically satisfactory spontaneous cures requiring no further treatment occurred in 2 patients submitted to sympathetic denervation, in 1 with traumatic sympathetic denervation, and in 10 with intact sympathetic function. In 1 patient only did the process leading to the spontaneous cure become evident soon enough after sympathectomy for a causal relationship to be considered a possibility.

In nearly all 18 instances of spontaneous cure the fistula or aneurysm had been temporarily stilled by digital compression once or several times, but the cure could hardly be said to have resulted from treatment by compression if only because compression had been employed in most of the patients in whom the lesion persisted until it was treated surgically.

Several cases are described in the literature in which aneurysms and arteriovenous fistulas disappeared after deliberate prolonged compression. Lyle,⁶ for instance, collected a number of cases in which aneurysms of the palmar arches were deliberately treated by this method. It hardly seems a desirable mode of treatment. For one thing, one could not be certain that thrombosis would be limited to the desired area, indeed it is quite possible that it might involve an uncontrolled extent of the affected artery and even of its collateral channels. The use of internal wiring to promote the development of a thick mural thrombosis in patients with inoperable aneurysm is often, of course, a palliative measure of great usefulness, but it was not employed in any instance in this series.

⁶ Lyle, H. H. M.: Aneurism of the palmar arches; with a report of an aneurism of the deep arch cured by excision. *Ann. Surg.* 80: 347-362, Sep 1924.

A number of observers, notably Reid,⁷ have suggested that the possibility of a spontaneous cure of an arteriovenous fistula might constitute a valid reason to delay surgical intervention for some months. If signs are observed which suggest the possible progressive spontaneous obliteration of either an aneurysm or an arteriovenous fistula, it would naturally be wise to follow this advice. The experience at the vascular center of Mayo General Hospital indicates, however, that the incidence of such satisfactory cures of arteriovenous fistulas, at least during the first few months after injury, is so low (2 percent), as to make this possibility a factor of little or no significance in deciding upon the proper time for surgical attack. The incidence of satisfactory spontaneous cures of arterial aneurysms was somewhat higher (6.7 percent), but again the occurrence seems so unlikely that the possibility is not a very important consideration in the selection of the proper time for the operative treatment of aneurysms.

⁷ Reid, M. R.: Abnormal arteriovenous communications, acquired and congenital; treatment of abnormal arteriovenous communications. *Arch. Surg.* 11: 237-253, Aug 1925.

CHAPTER XIII

Peripheral Vascular Disturbances Thromboangiitis Obliterans, Arteriosclerosis, and Arterial Thrombosis and Embolism

Norman E. Freeman, M. D.

THROMBOANGIITIS OBLITERANS

Thromboangiitis obliterans affected a small proportion of the patients admitted to the vascular centers established in the Zone of Interior hospitals during World War II. Thromboangiitis as encountered in the Army did not differ materially from the disease as observed in civilian practice except that it was usually observed in earlier stages; very few instances of longstanding involvement were seen.

Analysis of Data

Of the 3,778 patients with vascular conditions observed at the vascular centers during World War II, 274 had thromboangiitis obliterans; percentage-wise an incidence of 7.3 percent. All reported cases occurred in males. Of the 274 patients observed in the vascular centers detailed information was available for analysis on only 152 patients. In these 152 patients the great majority (122 patients) were in the age group between 26 and 40 years. The relatively low incidence (30 patients) under 26 years of age can probably be explained by the fact that the disease, although present in other soldiers in that age group, had not advanced sufficiently to produce symptoms.

As originally described (see Chapter II), the disease occurred in disproportionately large numbers among Jews. Information as to race was recorded in only 150 of the 152 in this series but in the 150 the distribution was as follows: 7 Negroes, 111 Caucasians, and 32 Caucasians of the Jewish faith.

Symptomatology and Clinical Course

As mentioned previously, very few cases of longstanding involvement were seen in the vascular centers. The range in a group of 53 patients observed at Ashford General Hospital may be considered as typical. In this group the duration of symptoms ranged from 1 month to 13 years, but averaged only about 22 months.

The distribution of symptoms presented at the time of the patients' admittance to the vascular centers was approximately the same as reported in other statistical surveys. Intermittent claudication, which Homans¹ has

¹ Homans, J.: Circulatory deficiency in the extremities in relation to medico-legal problems; arteriosclerotic deficiency (including diabetes); thromboangiitis obliterans, or Buerger's disease. *Ann. Int. Med.* 18: 518-534, Apr 1943.

termed "the one characteristic early evidence of the disorder," was the most frequent complaint and was observed in 67 percent of the 152 patients in this series. It was usually associated with pain in the foot and leg. Sixty percent of the patients complained of some form of pain in the extremities and 20 percent of some disturbance of sensation, chiefly numbness on walking. Temperature differences, either subjective or objective, were observed in 45 percent of the patients and migratory phlebitis in slightly less than a third. Ulceration was already present in 20 percent of the patients when they were first seen, though gangrene was unusual and was observed in only 4.4 percent of the patients. Nine patients had vasomotor disturbances characteristic of Raynaud's phenomenon.

Although the clinical manifestations of thromboangiitis obliterans were usually most noticeable in a single extremity, the disease is a systemic vascular disorder and careful examination frequently revealed that the blood vessels of other extremities were also affected. In almost two-thirds (65 percent) of the 152 patients, 2 or more extremities were involved, and in 13 patients all 4 limbs were affected.

Despite the widespread character of the involvement, visceral manifestations were unusual. In 3 patients attacks of precordial pain suggested the presence of disease of the coronary arteries. In 1 patient, who had suffered from thromboangiitis obliterans of the peripheral arteries for many years, quadriplegia and other neurologic manifestations developed while he was under observation. His clinical course indicated that the cerebral vessels had also become involved.

Diagnostic Procedures

In addition to a complete history and physical examination with particular attention paid to clinical evidence of vascular disturbances, certain special procedures were employed to establish the diagnosis of thromboangiitis obliterans. These were particularly necessary and of particular importance in a few patients who had been under examination and treatment on a variety of diagnoses in several installations before the correct diagnosis was made in one of the vascular centers.

The special procedures used to aid in the diagnosis of thromboangiitis obliterans included the accurate measurement of skin temperatures, oscillographic recordings of the peripheral arteries, arteriography, and biopsy studies. Constant temperature rooms were available at all of the vascular centers and were used to study the effect of varied degrees of coldness and warmth upon the skin temperatures of patients with thromboangiitis obliterans. In addition, skin temperature measurement and oscillographic readings were made before and after release of vasomotor tone by reflex vasodilatation, paravertebral injection of procaine, spinal analgesia, and peripheral nerve block. These procedures proved especially valuable in disclosing early involvement of small vessels as well as in the selection of appropriate patients for sympathectomy.

and were used in all patients indicated. Arteriograms (thorotrast was the contrast medium used) were made in 4 patients in whom arterial involvement was suspected but not confirmed by other diagnostic procedures. Peripheral pulses were normally present in each of the 4, but arteriography demonstrated that the circulation was maintained by means of collaterals. In 4 other patients the diagnosis was substantiated by biopsy of the affected vessels.

Therapy

Various forms of nonoperative and operative treatment were employed in the management of patients with thromboangiitis obliterans at the vascular centers in the Zone of Interior during World War II. It was generally agreed, however, that no type of treatment was effective unless the patient stopped smoking.

Nonoperative Treatment. Ever since Erb² first called attention to the close relationship between smoking and endarteritis, this aspect of the problem of thromboangiitis obliterans has been the subject of numerous clinical and scientific observations. Silbert,³ in an experience which covered 1,400 patients, observed no instance of the disease in a patient who had never used tobacco. Furthermore, he observed no instance of progression in 100 patients with the disease who gave up smoking completely and who were followed for over 10 years. He concluded, therefore, that thromboangiitis obliterans was caused by smoking in individuals constitutionally sensitive to tobacco. Horton,⁴ on the other hand, found thromboangiitis obliterans present in 68 of 948 nonsmokers. His position was that while there was no question that smoking had a decidedly bad influence upon the course of the disease, it did not necessarily follow that smoking was a cause.

Whatever may be the etiologic relationship between tobacco and thromboangiitis obliterans, it is generally agreed that abstinence from smoking is a mandatory part of therapy. Allen⁵ regarded it as "largely useless" to treat patients who continue to use tobacco and Homans⁶ said of the patient, "Above all, if he will not abandon tobacco smoking, his disease will almost necessarily persist and indeed will probably be aggravated."

It is known that only 4 of the 274 patients with thromboangiitis obliterans observed at the 3 vascular centers did not smoke. Information about their subsequent habits, after they had been warned to discontinue smoking, was obtained for 93 of these patients. Seventy-seven had stopped smoking entirely, and persistence of the symptoms was observed in only 2 patients in this group. Among the 16 who had continued to smoke, progression of the vascular obliteration was observed in 8 during the period covered by this investigation.

² Erb, W.: Ueber Dysbasia angiosclerotica, intermittierendes Hinken. München. med. Wehnschr. 51: 905-908, 1904.

³ Silbert, S.: Etiology of thromboangiitis obliterans. J. A. M. A. 129: 5-9, 1 Sep 45.

⁴ Horton, B. T.: Outlook in thrombo-angiitis obliterans. J. A. M. A. 111: 2184-2189, 10 Dec 38.

⁵ Allen, E. V.: Thrombo-angiitis obliterans. Bull. New York Acad. Med. 18: 165-189, Mar 1942.

⁶ See footnote 1, p. 375.

The opinion of the officers who directed the study and treatment of the patients with thromboangiitis in the vascular centers might well be summarized.

Capt. J. W. Kahn in writing of the experience at Ashford General Hospital reported that while smoking is not the cause of thromboangiitis obliterans, it is a very aggravating factor. Unless the patient stops smoking completely, no form of treatment, including sympathectomy, is of benefit. Recurrent migratory phlebitis has disappeared with the cessation of the tobacco habit alone. Wounds and gangrenous areas have cleared rapidly and pain has considerably improved when the patient stopped smoking. Following sympathectomy patients who still smoked complained of pain, but the pain was quickly relieved thereafter when the patient abstained. Gangrenous areas were slow in healing and demarcating when the use of tobacco was continued after sympathectomy, but gratifying results were noted when the smoking was stopped.

Maj. David I. Abramson in writing of the experience at Mayo General Hospital stated that it was felt at this center that no medication would be of any value if the patient did not abstain from smoking. When the diagnosis of thromboangiitis obliterans was made, the nature of the disease was thoroughly discussed with the patient, and the dangers of continuing to smoke were graphically illustrated by showing him the extremities of patients in an advanced stage of the disease. Most of the patients when informed of the relationship of smoking to the progress of the disease stated that they would abstain completely. However, in a number of instances it was subsequently brought to our attention that they had been unable to abide by their pledge.

At the vascular center of DeWitt General Hospital the inability of some men to abstain from the use of tobacco was recognized as a problem and was so studied. Silbert⁷ called attention to the " . . . extraordinary fact that some men will not stop smoking even when repeatedly warned that failure to do so will result in the loss of their extremities." Many of the patients seen at this center had previously passed through several medical installations. When the diagnosis of vascular disease was first suspected, most of them had been told by the medical officer that they "should stop smoking" or "should cut down on smoking," but the importance of complete and permanent abstinence from tobacco had never been stressed to them. In many instances the story was the same: The patient resolved to stop smoking and did stop temporarily, but resumed the habit. With each successive resolution and failure the process of stopping became more difficult.

Rather than adopt a defeatist attitude toward the problem, a policy was developed at the vascular center of DeWitt General Hospital in which each patient was permitted to decide the matter for himself. This plan was based on Homans' suggestion⁸ that "the individual should *know* that he will never

⁷ Silbert, S.: Treatment of thrombo-angitis obliterans. *Hebrew M. J.* 1: 155-149, 1942.

⁸ Homans, John: *Circulatory Diseases of the Extremities*. New York, The Macmillan Company, 1939.

smoke again." To accomplish this result each patient with thromboangiitis obliterans was instructed to *continue* smoking until he had realized two things: (1) that the diagnosis of thromboangiitis was irrefutable, and (2) that after considering the matter thoroughly and completely he had come to *know* he would never smoke again.

The patient must have no doubt about the validity of the diagnosis, and he must be convinced in his own mind that abstinence is the only solution to his problem. Time is required for the patient to arrive at this state of mind, but it was the experience at DeWitt that as soon as it was accomplished the soldier quickly adapted himself to the inevitable. Investigation showed also that the first time the patient stopped smoking was the one time he was most likely to succeed.

The patients were helped by being segregated into a nonsmoking ward where they were given special privileges. During the early period of total abstinence it was found helpful to use group suggestion, occupational therapy, and sedation. Much, of course, depended upon the personal relationship between patient and medical officer.

Under the aggressive policy outlined, the proportion of patients who succeeded in stopping smoking was greatly increased. In 39 successive cases there were only 2 failures. Horton⁹ has estimated that of those who do stop smoking 50 percent relapse, and it is realized that many of the patients who succeeded in stopping while at the vascular center may have returned to the habit after separation from the service and were doomed.

Provided the patient had stopped smoking, typhoid vaccine gave excellent results. The rationale of the use of typhoid vaccine is primarily the production of maximal vasodilatation as the result of the febrile reaction. The vaccine was administered intravenously and the dose was individualized in each patient so as to produce a febrile reaction up to 102° F. without causing a chill.

The injection of tissue extracts improved the ability to walk in about half of the patients. Various pancreatic tissue extracts, including padutin and depropanex, were used by the intramuscular route. While intermittent claudication was relieved in many of the patients by the use of these extracts, other features of the disease were not affected.

Only indifferent results were secured by the use of Buerger's postural exercises and physiotherapy, including intermittent suction and pressure, and intermittent venous occlusion, though they were employed in numerous cases.

Operative Treatment. Sympathectomy was performed for involvement of 1 extremity in 33 of the 152 patients in this series, and for 2 extremities in 18. In 2 patients 3 extremities were affected and sympathectomy was performed. The indications as well as the results, which were generally good, are discussed in detail in the section on sympathectomy in Chapter XVI.

⁹ See footnote 4, p. 377.

In 12 patients treatment consisted in repeated blocking of the lumbar sympathetic ganglia with procaine. Crushing of the peripheral nerves for the relief of intractable pain was employed in only 2 patients.

Disposition

In only 3 of the 274 patients in this series was major amputation of an extremity a necessity. However, only 24 recovered sufficiently to continue in the service; 3 returned to general duty and 21 to limited duty. The remainder were separated from the service by retirement or by Certificate of Disability Discharge.

COMMENT

It has been noted that thromboangiitis obliterans was observed in the vascular centers in World War II chiefly in the early stages of the disease. This may be explained by the fact that men suffering from clear-cut disorders of the peripheral circulation were rejected at the original physical examination; Jahsman and coworkers¹⁰ reported on the recognition of the disease in young draftees. It therefore seems probable that in most instances the disease developed during the time the patient was in the service. No evidence was obtained, however, that military service aggravated a preexisting disorder.

The fact that in 274 patients only 3 had to have major amputations of extremities, casts a hopeful light upon the therapy of thromboangiitis. The success can largely be attributed to the awareness by medical officers of the problem of vascular disorders which made early recognition possible, and the existence of specialized vascular centers staffed by experts and equipped to provide any therapeutic measures prescribed.

ARTERIOSCLEROSIS

Arteriosclerosis of the peripheral vessels sufficient to produce symptoms of vascular disturbances was reported in 55 patients from the 3 vascular centers in the Zone of Interior. The number is small but the incidence, in view of the age distribution of the personnel in the Army, is surprising. Although many observers believe that when arteriosclerosis is invoked as a cause of circulatory disorder the diagnosis should be looked upon with doubt if made upon individuals under 60 years of age, there was in the present series but 1 patient beyond that limit. The majority of patients fell into the age group 40 to 55 years. The youngest patient in the series was 30 and the average age was 45 years.

In more than half of the patients both lower extremities were affected. One lower extremity was involved in 6 patients and the upper extremities in 8. Intermittent claudication was present in 27 patients when they were first seen. Twenty complained of pain and 11 of abnormal coldness of the extremi-

¹⁰ Jahsman, W. E.; Durham, R. H., and Dallis, N. P.: Recognition of incipient thromboangiitis obliterans in young draftees. *Ann. Int. Med.* 18: 164-176, Feb 1943.

ties. A number presented evidence of systemic vascular disorders. Ten had cardiac disease, 5 hypertension, 3 diabetes, and 1 nephritis.

Diagnostic Procedures

Skin temperature determinations and oscillometric readings were useful in establishing the diagnosis of arterial insufficiency. Measurements of skin temperature after reflex vasodilatation or blockage of the vasoconstrictor impulses were made in 6 patients.

Special attention was paid to evidences of calcification as revealed by roentgenograms of the extremities. Calcification was observed in all the cases reported from the vascular center of Ashford General Hospital and in two-thirds of the patients reported from the other centers.

In this connection it was observed at Ashford that the incidence of calcification of the peripheral blood vessels in males between the ages of 30 and 40 years of age was remarkable. Capt. J. W. Kahn of this center reported on 10 patients in this age group who were sent to this hospital between March 1944 and September 1945 for vascular study because roentgenograms revealed calcification of peripheral blood vessels. Roentgenograms had been made for reasons other than vascular disease or vascular complaints and calcification was discovered accidentally. None of the patients in this group had any subjective signs of vascular incapacity nor, upon intensive vascular study, could they be found to have any objective signs of either organic or vasomotor disease. Oscillometric readings, skin temperature readings, and vasomotor tests were well within normal limits. None of the roentgenograms in this group revealed the spotty, mottled type of calcification; all showed smooth uniform shadows gradually fading into normal vessels proximally.

According to Captain Kahn, these findings are in keeping with the research of Huyler who studied calcification in a large series of patients for a number of insurance companies. The result of this research had revealed that those with the smooth type of calcification were relatively symptom-free as compared with those with the mottled type.

While none of the roentgenograms of the 10 patients revealed the spotty, mottled type, a number of the patients with firm, palpable, noncompressible, cord-like peripheral arteries failed to reveal any evidence of calcification. These patients, however, had other stigmata of generalized arteriosclerosis; the age group was higher and their symptoms were referable to cardiovascular-renal degenerative disease. The possibility of generalized atheromatous disease, without visible calcification, suggested to Captain Kahn a form of medial sclerosis of the Mönckeberg type.

It is well known that calcification in arteries can be shown by roentgenogram in only 35 to 40 percent of the patients with sclerotic disease. There is no question that relatively young patients presenting such findings will exhibit evidence of this disease at an earlier age than those in whom no evidence of calcification is found.

Therapy and Disposition

Lumbar sympathectomy was performed in 4 of the 55 patients, with satisfactory results in all. Other forms of treatment such as intramuscular injections of depropanex, intermittent venous occlusion, and physiotherapy were employed in a small number of patients. No major amputations were necessary, and only 1 minor amputation was performed.

Five patients were returned to limited duty. The remainder were separated from the service.

ARTERIAL THROMBOSIS AND EMBOLISM

There were 18 cases of spontaneous arterial thrombosis of unknown etiology reported from the 3 vascular centers. Case histories are not available to permit analysis.

There were 6 instances of embolism of the peripheral arteries reported from the vascular centers. Case histories are available for only 3 patients. In 2 of the 3, femoral embolism was followed by gangrene of the leg and amputation was necessary. The third patient had been successfully treated in an overseas hospital by embolectomy of the popliteal artery. When he was examined at one of the vascular centers, the pulses were found to be normal.

CHAPTER XIV

Peripheral Vascular Disturbances—Vasospastic Disorders—Raynaud's Syndrome and Raynaud-Like Disorders

Harris B. Shumacker, Jr., M. D.

and

David I. Abramson, M. D.

GENERAL CONSIDERATIONS

The vasospastic disorders are a group of peripheral disturbances in which the arterial circulation is impaired either intermittently and spasmodically or more or less continuously as a result of the tonic contractions of blood vessels. This group of diseases is differentiated from the obliterative arterial diseases by the general absence in the walls of the arteries of pathologic changes which would lead to narrowing or occlusion of the lumen. If, however, the vasospastic state is long continued, alterations of this kind may follow in certain of these conditions as, for example, Raynaud's syndrome, in which intimal thickening and thrombosis of the arteries may be observed late in the course of the disease. Furthermore, it is well known that vasospastic phenomena are frequently part of the clinical picture of obliterative vascular diseases.

Normally all components of the peripheral vascular system, including the main arteries and their branches, the arterioles, the capillaries, the arteriovenous anastomoses, and the veins, are under the control of the vasomotor center in the medulla which maintains its effect through innervation of these vessels by the sympathetic nerves. The vasomotor center and other portions of the sympathetic nervous system are influenced, in turn, by hormonal action, by various physiologic body functions, by the emotions, and by such external stimuli as warmth, cold, and noxious agents. All these factors play a part in regulating the caliber of the vessels. Normally the impulses traveling over sympathetic nerves are constrictor in action and maintain the blood vessels in a state of tonic contraction or tonus. Tonus is particularly evident in the arterioles and therefore plays a most important role in the regulation of blood flow and in the maintenance of peripheral resistance. The arteriovenous shunts, which are located chiefly in the digits and which are also richly innervated by sympathetic vasoconstrictor nerves, are important in the regulation of the temperature of the extremities, in the conservation and dissipation of body heat, and in the local vascular response to a cold environment. Tonus of blood vessels and variability in blood flow are much more evident in the

distal than in the proximal portions of the extremities or in the trunk. This phenomenon explains the predilection of the vasospastic disorders for the hands and feet.

The degree of tonus varies widely from individual to individual. Normally some persons tend to have low vascular tonus. Their hands and feet are warm and dry and maintain a relatively stable temperature under different environmental and emotional conditions. Others have a high vasomotor tonus. Their hands and feet are cold and moist and cool rapidly upon exposure to cold; they may cool and sweat profusely under emotion.

It is sometimes difficult to differentiate between the normal subject with a high vascular tonus and the subject with a mild but true vasospastic disorder. For all practical purposes, the same findings and the same reactions to a cold environment and to emotion may be present in both. Persons with high vascular tonus obviously have more complaints in cold than in warm climates. Furthermore, in one person a state of high vascular tonus and a responsive vasomotor system may cause no distress or inconvenience while the same symptoms in another person may constitute an annoying and perhaps disabling affliction. Numerous factors are responsible for these variations including climate, occupation, and personality makeup. Hyperhidrosis may be of no consequence in certain occupations but may be incapacitating to a chemist, an engineer, or others who must work with delicate weight balances. It was frequently observed in the course of World War II that a tendency to high vascular tonus which had caused no apparent inconvenience in civilian life sometimes led to annoying symptoms under the stress of a military regimen.

RAYNAUD'S DISEASE WITH DIGITAL SYNCOPE

In 1862 Raynaud¹ described the syndrome which now bears his name and which may be defined as a symmetrical vasospastic disorder characterized by phasic color changes in the digits which may lead to ulceration or gangrene in the absence of obliterative changes in the larger arteries. Since this syndrome was first described, a wide divergence of opinion has arisen over what really constitutes Raynaud's disease. Some have tended to group loosely together a wide variety of circulatory disorders in which the common factor is an abnormal responsiveness to cold. Others have attempted to limit the term Raynaud's disease to a progressive disorder which is not preceded by local injury or disease, which appears in early adult life or early middle age, which occurs chiefly in women, and which is characterized by symmetrical digital syncope or cyanosis upon exposure to cold or upon emotional excitation. Still others are of the opinion that a triphasic color reaction is an essential component of Raynaud's disease, the reaction consisting of blanching during the attack followed first by cyanosis, and then by rubor prior to restitution of normal color during the recovery period.

¹ Raynaud, M.: *De l'asphyxie locale et de la gangrène symétrique des extrémités*. Paris, Rignoux, 1862.

Although it has been recognized since Raynaud's original publication that the primary color change in the digits during the attack may be either pallor or cyanosis, and although the clinical course is identical regardless of the type of the color reaction, the data analyzed in this section of this chapter were obtained only from those patients in whom digital syncope occurred. This limitation is necessary because in 1 of the 3 vascular centers in the Zone of Interior a diagnosis of Raynaud's disease was made only in those patients in whom digital syncope was present during attacks. It was therefore impossible to determine from the data submitted by this center (Ashford General Hospital) which patients had true Raynaud's disease and which had acrocyanosis or some other vasospastic syndrome. A study of the data on Raynaud's disease as reported from the other vascular centers (Mayo General Hospital and DeWitt General Hospital) reveals that most patients affected with this difficulty had pallor during the attacks. For this reason exclusion of those patients in whom a cyanotic reaction was characteristic, actually omits from the analysis only a small proportion of the patients observed.

In view of the confusion which has arisen concerning the initial color changes in Raynaud's disease, and since the typical response to cold may occur in a variety of conditions, it has been suggested that the term Raynaud's disease might logically be replaced by the term Raynaud's phenomenon or Raynaud's syndrome. The rationale of the suggestion has been generally granted but the change in nomenclature has not been generally adopted. If and when it is, the term Raynaud's disease could be reserved for those patients with the syndrome in whom no definite etiology can be discovered and in whom intermittent episodes of digital syncope or cyanosis have been present for a relatively long period of time (not less than 2 years) without the appearance of signs of occlusive arterial disease.

Classification

Patients with so-called Raynaud's disease have been grouped in several different categories:

1. Patients with hereditary cold fingers. This is a mild condition which occurs in young persons and is characterized by blanching, cyanosis, or numbness of a few fingers on exposure to cold. Some authorities consider it a mild form of Raynaud's disease. The difficulty is seldom progressive and may become less severe or may disappear altogether with the passage of time.

2. Patients with pneumatic hammer disease. This disease, which is manifested by attacks indistinguishable from those of Raynaud's disease, results from prolonged use of vibrating tools.

3. Patients with a previous experience of frostbite. It has been questioned whether this disorder or the type of vasospastic disorder known as pneumatic hammer disease should be segregated from Raynaud's disease of unknown etiology since they are otherwise similar.

4. Patients with scleroderma and sclerodactylia associated with Raynaud's phenomenon. Opinions differ as to whether these diseases deserve a separate classification since they may be considered as cutaneous alterations which are a part of advanced Raynaud's disease itself.

Patients with acrocyanosis must be distinguished from those with true Raynaud's syndrome. In the former condition the hands or feet generally tend to be cool, blue, and wet except in an environment which causes extreme vasodilatation. Patients with this condition also have periods of marked responsiveness to cold and often to emotional stimuli. At such times there is an increase in cyanosis and coldness, though the color changes are not limited to these episodes.

Associated Disease

As has already been mentioned Raynaud's phenomenon occurs not infrequently in association with obliterative arterial disease and other conditions in which there is organic obstruction of the arterial blood flow such as thromboangiitis obliterans, arteriosclerosis, and arteritis of either specific or unknown etiology. It may also occur in association with a cervical rib, in the scalenus anticus syndrome, and in patients in whom the vessels have been compressed by crutches or by tumors. Before a diagnosis of Raynaud's syndrome is made, therefore, it is necessary to make certain that these and other organic obliterative or occlusive disorders and conditions are not present.

Clinical Material

One hundred eighty-four patients with Raynaud's disease with digital syncope were observed at the 3 vascular centers in the Zone of Interior during the course of World War II.² Ninety-seven patients were admitted to the Ashford General Hospital, 57 to the Mayo General Hospital, and 30 to the DeWitt General Hospital. Data were available for analysis on all such patients treated at the vascular centers of Mayo and DeWitt General Hospitals and on 40 of those handled at Ashford General Hospital, giving a grand total of 127 patients.

In all of these, digital syncope was observed by the attending medical officer, had been seen previously and described accurately in other medical installations, or had occurred so regularly and in so clear-cut a fashion that its presence could readily be established by interrogation of the patient.

² In addition to the patients with clear-cut Raynaud's disease with digital syncope and those with related vasospastic disorders but without digital syncope who are discussed in this chapter as distinct groups, a large number of patients were observed at the vascular centers who presented ill-defined vasospastic conditions. These patients formed a heterogeneous group and detailed analysis of the cases would be without profit. In most instances evidences of increased vascular tone and sympathetic overactivity were present under ordinary circumstances. In some instances only 1 limb was involved, but in a few all 4 were affected.

It is likely that in some of these patients the difficulty represented little more than a normally high vasomotor tonus to which attention was directed either by the stress of Army life or by the motivation of possible release from the service because of these complaints. Both of these theories are strengthened by the numerous and varied symptoms presented by the patients which could not be adequately explained upon organic or physiologic grounds. Ed.

Of the 127 patients 5 were Negroes and 122, Caucasians. One hundred eleven (87.4 percent) were males; 16 were females. Among Army personnel the annual admission rate for Raynaud's syndrome during World War II was five times as great among females as among males; the annual admission rate for females was .10 per 1,000 mean strength and .02 per 1,000 males.

The age range in this series was from 21 to 51 years; the average age 31.4 years. In two-thirds of the patients the disorder was of 2 years duration or less; in the remainder it varied from 2 to 24 years.

In a few patients the first attack appeared during cool weather but in the great majority it occurred during cold weather. In 46 of the 97 patients concerning whom such data were available, the onset occurred in the United States. In 21 it began in England, and in 15 others in France, Germany, Belgium, or Holland. In the remaining 15 it was first observed in Alaska, Australia, Iceland, Iran, Italy, and North Africa. In only 5 of 57 patients from the Mayo General Hospital questioned on this point did the symptoms arise either during or immediately before conditions of combat.

Attacks were initiated in all instances by exposure to cold. The critical temperature, however, varied widely. Some patients experienced blanching of the fingers in slightly cool weather, but in most instances the phenomenon was observed only during severe cold. Only 14 of the 97 patients for whom such data were available gave a history of the precipitation of attacks by emotional excitement or stress and in 10 of the 14 some neuropsychiatric disorder or emotional instability was found. In 8 other patients who were found to have psychiatric disabilities emotion played no role in producing the color changes in the fingers.

Etiology

Frostbite antedated the first appearance of the Raynaud phenomenon in 16 patients in most of whom the exact time relationship was not known. In 2 of 6 patients questioned on this point at Mayo General Hospital, frostbite preceded by a number of years the onset of Raynaud's phenomenon, while in the other 4 patients, attacks of digital syncope appeared immediately after frostbite had been sustained and became progressively more severe with the passage of time. Two of the 57 patients with Raynaud's syndrome at the Mayo General Hospital had used vibrating tools for some years prior to the onset of Raynaud's disorder.

Clinical Manifestations

Twenty of the 57 patients studied at the Mayo General Hospital showed all the features which have been regarded as classical in Raynaud's phenomenon. (Figs. 51A, B, C, and D.) The involved digits, immediately upon exposure to cold, would turn dead white and the patient would experience in them the sensation of intense coldness, numbness, and stiffness. A clear-cut line of demarcation was generally present between the portion of the digit showing

the pallor and that retaining normal color. After a variable interval following return to a warm environment, the digits would become cyanotic; cyanosis was followed by a period of rubor which was succeeded, in turn, by return to normal color. During the late stages of the attack most patients complained of tingling, throbbing, and burning sensations or other paresthesias.

The triphasic color reaction was not present in the other 37 patients observed at Mayo General Hospital. In 16 patients cyanosis followed the pallor and was succeeded by a return to normal color, the phase of rubor being omitted. Eleven patients experienced rubor immediately after syncope, the phase of noticeable cyanosis being omitted. In the remaining 10 patients digital syncope was followed directly by return of normal color. In all instances, however, the initial response was either pallor or cyanosis, with pallor much more frequent. It was the general experience that digital syncope could be more regularly elicited by exposure to a cold environment or by taking a cold shower than by immersion of the limb in ice water.

The syncope affected varying numbers of digits and varying portions of digits. In some patients only the tips of the fingers or toes were affected. In others the changes occurred in the distal phalanx, the distal and middle phalanges, or the entire digit. In some patients only a single digit became blanched while in others all 5 were affected. In a number of patients blanching occurred initially in only 1 limb with involvement of the contralateral extremity occurring later. In a number of patients with symmetrical involvement the phenomenon was observed first in 1 or 2 digits in a single extremity and later it was noted to spread progressively to other portions of the hand or foot and eventually to the contralateral limb.

Of 47 patients about whom these data were recorded at the Mayo General Hospital, 27 had involvement of the second, third, fourth, and fifth digits of both hands or both feet, while some of this group also had involvement of the thumb and great toe. Unfortunately, recorded data were not always specific on the latter point. In 5 patients, 2 or 3 digits were symmetrically involved and in another the symmetrical response was observed in a single digit. Fourteen patients had asymmetrical distribution of the syncope; of this number, 8 exhibited syncope of 1 or several digits in only 1 limb.

The upper extremity was more commonly affected than the lower. In the aggregate of 127 patients analyzed, both hands were affected in 69 (54.3 percent), one hand or the other in 7 (5.5 percent), both hands and feet in 45 patients (35.4 percent), one hand and one or both feet in 3 patients (2.4 percent), both feet in 2 patients (1.6 percent), and 1 foot in 1 patient (0.8 percent).

Blanching and symptoms did not necessarily coincide. A number of patients had experienced numbness, coldness, stiffness, and paresthesias in the involved limbs and digits years before the onset of the attacks of digital syncope. In others, although the symptoms were usually worse on the side exhibiting pallor, exposure to cold frequently elicited similar complaints in



Figure 51. Typical digital syncopal changes in patient with Raynaud's disease on exposure to cold. A. Dorsal surface of fingers. B. Palmar aspect. Marked loss of the subcutaneous pulp of the fingertips occurred in this patient within a few weeks after the onset of symptoms. C. Dorsal aspect of hands after bilateral sympathectomy. D. Appearance of fingers (palmar view) after bilateral sympathectomy. The subcutaneous pulp of the fingertips regained its normal appearance shortly after operation.

the contralateral limb in which color changes were not present. It was quite possible for these symptoms to be incapacitating in the absence of color changes. Two patients in whom sympathectomy was performed because of the frequent occurrence of blanching associated with symptoms in an upper extremity, expressed the desire after they were separated from the service to have the same procedure carried out on the other extremity in which syncope had never occurred but in which marked symptoms were being experienced.

In the interval between attacks many patients were completely asymptomatic and circulation was normal. About half of the patients seen at the Mayo General Hospital, however, had at all times some evidence of excessive sympathetic activity, manifested either as cool, moist, and slightly cyanotic hands and feet or in the form of coolness and excessive sweating. Still others, although their limbs were normal in warmth and color, experienced moderate hyperhidrosis. As a rule, symptoms experienced between acute attacks were mild.

Trophic changes occurred in 20 of the 127 patients (15.7 percent). In most instances they were slight and consisted of little more than slight distortion of the nails or slight thickening of the skin. In a few patients in this group, however, the skin covering the fingertips seemed actually to be separated from the deeper tissues. Pressure applied in this area produced a temporary dimpling; after release of pressure the skin ballooned out again. In 5 instances scleroderma or sclerodactylia was present. One patient (Fig. 52A) had small areas of bilateral gangrene of the fingertips.



Figure 52. A. Patient with longstanding Raynaud's disease showing bilateral superficial gangrene of fingertips. B. Complete healing of ulcerative areas shortly after bilateral dorsal sympathectomy.

In an occasional patient trophic changes occurred very early in the disease, in 1 instance there was a well marked loss of subcutaneous pulp within a few weeks of the onset of symptoms. Livedo reticularis, which is actually not a trophic change, was observed in 2 of the 57 patients treated at the Mayo General Hospital (Figs. 53A and B).

Circulatory Tests

Examination of the peripheral circulation in a warm environment consistently revealed no abnormalities in any of the patients in this group. Except for the occasional absence of the dorsalis pedis pulse on one or both sides, all the pulses in the extremities were readily palpable. No signs of arteriosclerosis were noted. Various simple procedures for the determination of the state of the circulation such as the plantar pallor test, the venous filling time, oscillometric recordings of arterial pulsations, and the production of local vasodilatation by means of body heat or paravertebral sympathetic block with procaine, all indicated that no organic vascular disease existed in these cases.

Therapy

The majority of the patients in this series were separated from the service without active treatment. Prior to their separation their vascular status was discussed with them and they were advised to stop smoking, to attempt to control their emotions, if the emotional factor was believed to be important in precipitating the color changes, and to live in a warm environment if possible. If it was not, they were told to attempt to avoid exposure to cold and were given advice on how to dress during the winter. If the number or severity of the attacks was distressing or incapacitating, or if nutritional disturbances existed, sympathetic ganglionectomy was performed.

One hundred sympathectomies were performed upon 46 of the 127 patients. Spread of the denervation was as follows: In 5 patients all 4 extremities, in 4 patients 3 extremities, in 31 patients 2 extremities, and in 6 patients 1 extremity.

At Mayo General Hospital 21 sympathectomies were performed upon 9 patients. Since both of us were able to follow the patients closely during their period of hospitalization the results of the experience at Mayo are presented herewith:

With one possible exception the immediate therapeutic effects were excellent in all patients (Figs. 51-53). In the single exception all 4 extremities were denervated in 4 stages. Although after each operation the patient felt sufficiently relieved to desire the next stage, at the completion of the procedure he was in doubt about the total benefit he had received. He no longer had attacks of digital syncope and had relatively stable circulation in the extremities, but experienced tingling sensations in cold weather. He also suffered from annoying, and at times incapacitating, hyperhidrosis of the trunk in warm weather. Another patient who had had all 4 extremities denervated also suffered from excessive sweating of the trunk in hot weather or with exercise, but to him the relief of vasospasm far outweighed this annoyance.

All of the remaining patients had warm, dry, well-colored extremities which tended to cool slowly upon exposure to cold. They ceased to have attacks of syncope. Those who had lost pulp in the tips of the fingers had a striking



Figure 53. A. Marked livido reticularis of lower extremities in patient with Raynaud's syndrome. B. Appearance of feet following bilateral lumbar sympathectomy. Note improvement in livido reticularis.

restoration to normal following operation (Fig. 51B). The areas of gangrene present in a single patient healed promptly and the marked livedo reticularis noted in another patient (Fig. 53A) cleared to a considerable extent after operation (Fig. 53B).

OTHER VASOSPASTIC DISORDERS

In addition to the patients with Raynaud's disease observed at the vascular centers in the Zone of Interior, 135 other patients treated at these centers suffered from a vasospastic disorder characterized by abnormal responsiveness to cold but not by clear-cut digital syncope. The findings varied in respect to the type of reaction to cold, the severity of the symptoms, and the vasomotor tonus under ordinary environmental conditions. Some patients fell into the category of true acrocyanosis. A few presented a syndrome similar to Raynaud's disease except for the absence of digital syncope. Others had a history of attacks in which they thought blanching had occurred but the color change, judging from the patients' descriptions, was either not definite or took place infrequently.

Clinical Material

One hundred seven of the 135 patients in this group were observed at the Ashford General Hospital, 22 at the Mayo General Hospital and 6 at the DeWitt General Hospital. Data for analysis were available in 55 cases. Fifty-two of the 55 patients were males and 3 females. Two were Negroes. The age range was from 19 to 45 years, the average about 30 years. In almost three-fourths of the patients the disorder was of 2 years duration or less. In the remaining patients it had been present for periods ranging from 2 to 38 years. In 10 of the 22 patients observed at the Mayo General Hospital the vasospastic difficulty began in the Zone of Interior. In 5 patients it began in England, and in 4 in France or North Africa. In the other 3 patients the place of onset was not recorded.

Etiology

In 3 of the 55 patients there was a history of antecedent frostbite but in only 1 of these was information available concerning the exact interval between the thermal injury and the first note of an abnormal response to cold. This patient reported that a progressively severer sensitivity to cold had developed shortly after a mild frostbite which had been sustained 3 years earlier. Scleroderma had been present in both hands for about 9 months before he had entered the hospital. Two patients had used vibrating tools before the development of the disorder. Infected ulcers of the fingertips were present in 1 of these patients.

Therapy

For most of the patients in this group no active treatment was instituted. According to the severity of their disorder they were returned to duty or sepa-

rated from service, with the advice to abstain from smoking and to avoid if possible exposure to cold. If the condition was advanced, a move to a warm climate was suggested.

Twelve sympathectomies were performed upon 6 patients. Spread of denervation was as follows: In 1 patient all 4 extremities, in 1 patient both upper extremities, in 2 patients both lower extremities, and in 2 patients 1 upper extremity.

Immediate results were good in all. The extremities became warm, dry, and well colored and were no longer abnormally sensitive to cold. There was dramatic improvement in the condition of the patient who had lost subcutaneous pulp from the fingertips, and in the patient with scleroderma there was lessening in the degree of involvement as well as relief of symptoms.

COMMENT

The term Raynaud's syndrome should be reserved for cases in which transient digital syncope or cyanosis occurs upon exposure to cold or upon emotional excitation. By commonly accepted definition those patients with cold sensitivity but without significant color changes upon exposure to cold should be considered to present not Raynaud's syndrome but rather Raynaud-like disorders. Those with persistent cyanosis and coldness who do not manifest transient alteration in color of the digits should be placed in the category ordinarily diagnosed as acrocyanosis.

One of the criteria generally accepted as necessary for the diagnosis of Raynaud's disease is bilateral and symmetrical involvement of the extremities. In approximately 6 percent of the patients with clear-cut digital syncope in this series, however, only one extremity was involved. The explanation may be that many of these patients, because they were in the service, were seen earlier than they would have been seen in civilian life, and it is possible that the earlier the patient is observed, the more frequently will the disease be noted in one limb alone.

In approximately two-thirds of the patients at Mayo General Hospital the classical triphasic color reaction was not present. This brings up the question of whether the triphasic color response is necessary for the diagnosis. It was the consensus at the vascular centers that the diagnosis of Raynaud's disease can reasonably be entertained in the presence of vascular attacks of digital syncope or cyanosis elicited by exposure to cold or emotion, whether or not the triphasic color reaction is observed, provided no etiologic factor can be established for the condition and if signs of obliterative vascular disease are absent. Furthermore, it does not appear to be necessary for either cyanosis or pallor to be replaced by rubor as a preliminary step to the return of normal color when the extremity is exposed to a warm environment. Although segregation of patients according to the presence or absence of digital syncope is a purely artificial classification, it has been employed in this analysis, as has been explained, because the

diagnosis of Raynaud's disease was made upon this basis at one of the centers. To be sure, the dead white character of the change is so striking that it affords one means of definitely differentiating patients with a true Raynaud's phenomenon from others with cold sensitivity alone. Furthermore, it was noted, in comparing the patients showing digital syncope with those falling into the same category but without this response, that the vasospastic difficulty was generally more severe in the former group. Nutritional disturbances were also more frequently present in this group, although in at least 2 cases typical trophic changes were also noted in the group of related cases without digital syncope.

Another interesting point of differentiation is the observation that in patients with digital pallor the hands were frequently affected alone, or, if all four extremities were involved, more severely than the feet. In the other group without digital pallor, approximately a third of the patients showed changes in the feet alone. In this group the entire hand or foot was likely to be affected, while in patients with digital syncope the change in color was usually limited to the digits.

The present series confirms what is generally known concerning the treatment of Raynaud's phenomenon and similar syndromes. If the difficulty is severe, if nutritional disturbances are present, if the process cannot be controlled by suitable climatic conditions, sympathectomy offers the best means of relief. This analysis furnishes support for the general experience concerning the excellence of this procedure. If the severity of the symptoms does not make it imperative, sympathectomy of all four extremities is to be avoided because of the discomfort which may result in warm weather from hyperhidrosis of the trunk.

Examination of the available data from the Army vascular centers reveals that 87.4 percent of the 127 patients having Raynaud's disease with digital syncope, and 94.5 percent of the 55 patients with vasospastic disorders but without digital syncope, were men. Since all of the patients in the first group, and some in the second, were instances of true Raynaud's disease, this series presents further confirmation for the view that though this disorder occurs primarily in females, it affects males as well. The great predominance of males in this series, as compared to the 23 percent reported by Hines and Christensen³ in a group of civilians, is readily explained by the overwhelmingly predominance of males in the Army. The analysis also confirms the view that Raynaud's disease and comparable conditions as they occurred in the Army were quite similar to the same disorders as they are observed in civilian life.

It has been the general impression that transient episodes of color changes in the digits of the male are usually secondary manifestations of occlusive arterial disease. This opinion is not supported by the observations in the vascular centers. Although some cases of obliterative arterial disease associ-

³ Hines, E. A., Jr., and Christensen, N. A.: Raynaud's disease among men. *J. A. M. A.* 129: 1-4, 1 Sep 45.

ated with Raynaud's syndrome were seen, in none of the patients in this series was there evidence that this type of arterial disease existed or that it might subsequently appear. On the other hand, observations of these patients were limited to a period of months, and whether or not some will subsequently have demonstrative evidence of organic vascular disease and will no longer fall into the category of Raynaud's disease can be determined only by followup studies. It is important to emphasize, however, that nothing to suggest obliterative arterial disease was evident during the period of hospitalization.

The theory that the stress and strain of Army life may be a factor in the precipitation of peripheral vascular disorders is not supported by the findings in this series. In a considerable number of patients the attacks began in civilian life and in only a small percentage did the disorder arise under conditions of combat or just prior to such activity. Emotional stress and excitement initiated the color changes in 14 of 97 patients concerning whom these data were available, while emotional instability or other neuropsychiatric disorders were present in 18 cases. These proportions are somewhat similar to those of Hines and Christensen⁴ who reported that in 9 of their 100 male civilian patients, attacks occurred with emotional excitation and that functional or neurotic disorders were present in 29 patients. Nevertheless, military life may have been a factor in some instances. Soldiers are exposed to cold weather to a far greater extent than they are in civilian life and such exposure might aggravate a vascular disorder already existent or bring into activity a latent disturbance.

In a number of patients with digital syncope studied at Mayo General Hospital the onset of attacks was antedated by frostbite. In 1 of the 22 cases of Raynaud-like syndrome without digital syncope observed at the same hospital, extremely severe vasospastic disease followed a service-incurred frostbite. The use of vibrating tools may possibly have been an etiologic factor in 2 of the 57 patients with digital syncope and in 2 of the 55 in the group who did not show this response, though in each of these instances the instruments were used in civil life many years before the onset of the attack.

In spite of the fact that Raynaud's disease and similar disorders seldom resulted directly from military service, ill-defined heterogeneous difficulties with associated vasospasm often followed, or were aggravated by, the stress of Army life or by the motivation to be separated from the service. Though many men with Raynaud's disease and similar disorders served well in the Armed Forces, it is believed that, in general, the Army policy of considering such persons as ineligible for induction or enlistment was well founded.

⁴ See footnote 3, p. 393.

CHAPTER XV

Peripheral Vascular Disturbances Post-Traumatic Vasomotor Disorders

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Although injury to an extremity is generally followed by signs and symptoms readily explained upon the basis of the trauma sustained and the resultant dysfunction, there are in certain instances other changes superimposed which can be accounted for only on the assumption that some reflex disorder has been initiated by the local tissue damage.

Since 1900, when Sudeck¹ first described a syndrome in which acute atrophy of bone followed an inflammatory process, this reflex post-traumatic state has been the subject of numerous studies and has attracted widespread interest. The many terms² which have been employed to describe this clinical condition bear witness not only to the widespread disturbances that may occur but also to the lack of agreement on what constitutes the characteristic primary alteration. The most constant finding is some type of vasomotor dysfunction. In the affected limb there is usually increased vasomotor tonus or hyperemia, also increased blood flow. Because of such manifestations, the comprehensive term post-traumatic vasomotor disorders would seem the most appropriate designation for the whole group of heterogeneous reflex affections which may follow trauma.

This category of post-traumatic vasomotor disorders does not include such related conditions as major causalgia and phantom limb pain which are syndromes with such characteristic features that they are best considered as separate entities. Marked sympathetic overactivity may be present in certain instances of occlusion or division of peripheral arteries as the result of trauma. In those conditions, however, in which the occlusion of the vessel has a significant effect upon the nutrition of the extremity, part of the subsequent difficulty arises from the direct decrease in the local blood flow, and this type of vasospastic alteration is likewise best separated from the post-traumatic vasomotor disorders. There is also good reason to exclude from this group the vasospastic states which follow cold thermal injuries, that is, frostbite, trenchfoot, and immersion foot, as well as the vasospastic states associated with deep thrombophlebitis. Finally, those vasospastic disorders which

¹ Sudeck, P.: Ueber die acute entzündliche Knochenatrophie. *Arch. f. klin. Chir.* 62: 147-156, 1900.

² Among the names which have been given to the syndrome are the following: Sudeck's atrophy, acute bone atrophy, post-traumatic osteoporosis, post-traumatic painful osteoporosis, traumatic arthritis, peripheral trophoneurosis, reflex nervous dystrophy, reflex sympathetic dystrophy, post-traumatic dystrophy, minor causalgia, traumatic angiospasm, chronic traumatic edema, and post-traumatic edema.

are apparently the sole result of disuse do not belong in the category of post-traumatic vasospastic disorders. All of the conditions just listed have a number of features in common, but each possesses certain special characteristics which make it advisable to deal with it as a distinct syndrome.

It is generally accepted that the primary mechanism responsible for post-traumatic vasospastic disorders is some type of reflex disturbance initiated by the local injury. It is also accepted that the components of the sympathetic nervous system are in some manner involved in the reflex arc. Beyond this, no agreement has been achieved. Numerous theories have been advanced, but no definite proof exists to establish the correctness of any. Similarly, no agreement has been reached concerning the real cause of the osteoporosis which so commonly occurs in association with post-traumatic vasomotor dysfunction.

Concerning the true incidence of these late complications of injuries no data are available, but the series of cases analyzed in this chapter may be assumed to be representative with respect to both clinical manifestations and response to therapy.

Because the patients were seen after they had been treated in other Army installations, information concerning initial manifestations and early therapy is subject to the criticism that it was collected by other observers. Every effort, however, was made to reconstruct the sequence of events and the results of early treatment through a careful perusal of prior clinical records, plus detailed questioning of each patient with regard to early phases of his condition. Data concerning late manifestations and results of late treatment are based upon close personal observations during the period of hospitalization.

It is important to bear in mind in any analysis of a post-traumatic vasomotor disorder that the patient with a limb painful or swollen, or in which there is annoying coldness or hyperhidrosis, has a strong tendency to keep it at rest, and that disuse may of itself cause certain alterations which are characteristically considered part of the post-traumatic syndrome, namely, reduction of blood flow, coldness, cyanosis, hyperhidrosis, edema, and osteoporosis. For this reason it is often difficult to evaluate the relative roles of trauma and of the reflexes initiated by trauma, on the one hand, and of the resultant disuse of the part on the other. Furthermore, it is important to recognize that emotional stress or instability and other more pronounced neuropsychiatric conditions may also be associated with evidences of increased sympathetic activity. Persons who have undergone trauma may bring these psychiatric mechanisms into play as the result of discouragement concerning recovery, because of motivation for compensation, or because of the hope of other rewards of incapacitating illness including avoidance of duty in the Army. In any evaluation of vasomotor difficulties following service-incurred trauma it is necessary, therefore, to keep in mind the possible role of both disuse and psychiatric factors.

CLINICAL MATERIAL

One hundred and forty-two patients, all males, with post-traumatic vasomotor disorders were received in the vascular center of Mayo General Hospital during World War II after they had been treated at other Army installations. In 1 instance 2 limbs were affected in the same patient. The age range in this series was from 20 to 38 years, the average age, 27 years.

The disorder became manifest after soft tissue wounds in 58 patients, after sprains in 19, and after crushing or other external injuries in 11. In 14 patients it followed compound fractures of small bones, and in 7, simple fractures of such bones. In 24 patients it resulted from compound fractures of long bones, and in 5, from simple fractures of these. In 3 it was the consequence of infection, while in 1 patient the surgical removal of a small cyst was apparently the initiating cause. In addition to the precipitating injuries just listed, 19 patients had associated nerve paralysis and 4 had sustained lacerations of minor arteries. One had incurred a mild frostbite at the time of injury.

A foot was affected in 110 patients and a hand in 31. In addition, 1 soldier had vasomotor disturbances in an upper and a lower extremity following injuries to these. In patients without a previous tendency to coldness of the hands or feet, evidence of increased vasomotor tone was frequently present not only in the injured limb but also to a lesser extent in the contralateral limb; sometimes these manifestations were present in all 4 limbs. In such instances the symptoms in the uninjured extremities were generally slight, although 1 soldier developed such severe cold sensitivity in both hands following injury to the left forearm that he required bilateral dorsal sympathectomy.

In all but 1 patient the vasomotor disorder began during Army service. Twenty-five patients, however, had had a tendency to coldness of the hands or feet prior to the vasomotor difficulty, and an equal number had noted hyperhidrosis in varying degrees in the past. A history of previous injury to the affected limb was obtained in 5 individuals, and of frostbite or trenchfoot in 4. Eighty patients used tobacco. There was no really relevant family history in any of these although such vascular difficulties as varicose veins, vascular thrombosis, or hemorrhage had occurred in the families of 12.

CLINICAL SYNDROME

Initial Symptoms and Signs. The most usual story elicited on questioning of the patients was that severe pain associated with swelling, coldness, and cyanosis, often with excessive sweating, developed in the affected hand or foot shortly after injury. Active use of the extremity was impossible because of pain on movement or on weight-bearing. A few had no significant pain but instead noted evidence of excessive sympathetic activity, such as coldness, cyanosis, and hyperhidrosis. In some, edema, out of proportion to the injury sustained, was the most striking finding, while in others increased vasomotor

tonus without edema was noted. Marked weakness of the involved limb was almost constantly present. In a number of instances weakness of the affected limb amounted to virtual paralysis. In the order of frequency, the most prominent initial symptoms and signs obtained through questioning and a study of clinical records were as follows: pain in 97 patients, swelling of the affected hand or foot in 95, cyanosis in 93, coldness in 72, hyperhidrosis in 52, numbness in 26, and pallor in 3.

The symptoms listed were generally noticed within periods ranging from several days to a few weeks after injury. In some patients, however, whose initial trauma required immobilization of the limb in plaster, signs and symptoms suggestive of a post-traumatic vasomotor disturbance did not become evident until the cast was removed and the man became ambulatory. The preceding complaints could be explained solely on the basis of the local tissue injury.

It should be pointed out that there was nothing in the history or the clinical record of these patients to suggest that the early circulatory alterations recorded were the result of vasodilatation and increased blood flow, as Miller and De Takats³ have observed in some patients in civil practice. In practically all of the combat-incurred post-traumatic vasomotor disorders, the prominent initial findings were those of sympathetic overactivity.

Initial Therapy. While details of the early therapy applied to the patients under discussion are unfortunately meager, it is quite clear that in the majority of instances no active effort was made during the first few weeks after wounding to treat anything but the local injury. Wounds were properly debrided and foreign bodies excised when these procedures were indicated. Limbs in which fractures had been sustained were immobilized in plaster. These measures seem to have been adequately applied. Only a few patients were treated by casts when there was no fracture or other specific indication for this measure. Compresses were applied locally and sulfonamide drugs given by mouth or penicillin administered parenterally when infection was present.

When it became apparent that some profound vasomotor disturbance was superimposed upon the local injury, other methods of treatment were instituted. Methods most commonly employed were contrast warm and cold baths, whirlpool baths, Buerger's exercises, massage, and local heat. Little serious effort seems to have been made to establish early active motion and weight-bearing. Sympathetic blocks were employed in 32 patients but in only 2 were they done during the first month of the vasomotor difficulty. One of these patients showed continued improvement after 2 blocks had been carried out during the second week following injury. When examined several months later he had few sequelae. The other patient derived transient benefit from a single block performed on the day of the injury, and significant and lasting improvement from several more performed 5 months later.

³ Miller, D. S., and De Takats, G.: Post-traumatic dystrophy of the extremities. Sudeck's atrophy. *Surg., Gynec. & Obst.* 75: 558-582, Nov 1942.

Late Symptoms and Signs. An average of about 5½ months elapsed between occurrence of the initial injury to patients included in this series, and the time of their admittance to the Mayo General Hospital. In the interval the correct diagnosis had usually been established although some conditions were still considered to be caused by deep venous thrombosis, thromboangiitis obliterans, or some other primary vascular disorder.

In Table 48 are listed the chief complaints elicited on admittance and the physical findings noted upon examination. Pain, edema, coldness, and cyanosis were still the most common symptoms. Nearly one-fifth of the patients had sensitivity of the affected part to cold; in a few instances this disturbance was extremely severe. Other patients complained of stiffness or numbness. Some had chronic ulceration. Pain was primarily experienced on weight-bearing or other activity. Although it was commonly described as an aching sensation, it was throbbing in some instances and burning in others. In most cases it prevented normal physical activity and its long duration had usually completely destroyed the patient's confidence in his ability to use the affected limb properly. Two patients had moderate burning pain when the limb was at rest, but its inconstancy eliminated true major causalgia from consideration as a diagnosis.

TABLE 48. SYMPTOMS AND SIGNS IN POST-TRAUMATIC VASOMOTOR DISORDERS

<i>Chief complaints elicited on admittance (142 patients)</i>		<i>Patients</i>
Pain.....		97
Edema.....		94
Coldness.....		80
Cyanosis.....		67
Hyperhidrosis.....		54
Sensitivity of part to cold.....		*26
Stiffness.....		24
Numbness.....		16
Chronic ulceration.....		5
<i>Signs present on admittance (142 patients)</i>		
Muscle weakness.....		142
Cyanosis.....		99
Affected limb cooler than contralateral one.....		80
Hyperhidrosis.....		80
Edema.....		70
Muscle atrophy.....		59
Affected and contralateral limbs cool or cold but equal in temperature.....		40
Stiffness of joints.....		30
Hypesthesia.....		23
Affected limb warmer than contralateral one.....		22
Rubor.....		13
Chronic ulceration of skin.....		5
Pallor.....		3

*Very severe in 6.

Of the 111 patients with vasomotor difficulties involving the lower extremities admitted to the vascular center of Mayo General Hospital, 21 were confined

to bed when first admitted, 32 were ambulatory with the use of crutches, and 16 more could get about with canes. Forty-two walked without aid but with a definite limp. Those with involvement of the upper extremities tended to guard the affected limb and to avoid using it.

In every instance examination revealed motor weakness of the affected limb (Table 48) which sometimes amounted to virtual paralysis. Muscle atrophy was commonly evident and stiffness of the joints quite frequent. Hyperesthesia was occasionally present but not always associated with a definite sensory nerve injury. Edema of varying degrees was present in about half of the patients. (Fig. 54A and B.) In some instances it was massive even after prolonged bed rest (Fig. 55A and B) in a few it was present despite elevation of the extremity, but in the majority it was mild or moderate. Cyanosis was observed in the majority of patients, in the horizontal position in some instances but in others only in dependency. Rubor and pallor were uncommon. Hyperhidrosis of varying degrees was often present; in some patients the sweat literally ran off the involved hand or foot.

The affected member was generally cool or cold. In the majority of patients accurate thermocouple studies of skin temperature were carried out; in the remaining, temperature was judged by palpation alone. In 80 instances the affected limb was cooler than the contralateral uninjured limb. In some of these patients the differences in temperature were considerable while in others they were slight, especially when the normal limb was itself excessively cool. In 40 in whom temperatures of the abnormal and normal extremity were approximately equal, both limbs tended to be cool or cold. In some of these individuals the affected limb cooled more rapidly than the uninjured limb upon exposure to a cold environment.

In 22 patients the involved hand or foot was warmer than the contralateral limb. In 21 of the 22, the thermocouple readings of the affected part were at the lower level of the normal range or even cooler. In the remaining patient the skin temperature was abnormally high as a result of infection.

In 88 patients oscillometric and skin temperature studies were made with the following results:

Oscillometric and temperature recordings less than in normal extremity.....	32
Oscillometric readings less and temperature equal.....	17
Oscillometric readings and temperature approximately equal.....	14
Oscillometric readings less but temperature higher.....	10
Oscillometric readings equal and temperature less.....	10
Oscillometric readings and temperature greater than in normal extremity.....	3
Oscillometric readings greater but temperature less.....	2

One notable observation on physical examination of these patients was that, although all had evidence of some vasomotor alteration and many presented edema, cyanosis, coldness, and hyperhidrosis, a considerable number exhibited some one of these changes out of proportion to the others. For example, some individuals suffered from intense cyanosis without a great deal

of edema, coldness, or increased sweating. Others presented massive edema with minimal changes in color, temperature, or sweating. Still others showed extreme local reduction in temperature or considerable hyperhidrosis or both, without significant edema or cyanosis.

Most of the patients had assumed the attitude and behavior of the chronic invalid. They were weary from prolonged disability and hospitalization and their viewpoint toward the possibility of eventual recovery was usually hopeless or relatively hopeless. Some appeared to embrace the concept that their condition was sufficiently disabling for them to look forward to separation from the service. In only 11 of the 142 patients, however, was a true neuropsychiatric disorder diagnosed by psychiatric consultants. In this small group the general attitude and behavior differed in no great degree from the attitude and behavior of the group as a whole except that a few showed evidences of anxiety. On the other hand, all 11 patients had certain local findings which were helpful in segregating them from other patients. The most common observation was a forced effort in response to a request to perform a certain movement. The effort was associated with a gross tremor or with little or no movement of the part but with obvious contraction not only of the muscles ordinarily utilized in the movement requested but of their antagonists as well. When, for example, a patient was attempting to extend his foot in response to a request, it was often apparent that both the extensors and the flexors were being brought into a state of tonic contracture so that no movement at all resulted except possibly a coarse tremor. This sign, more than any other, was helpful in establishing the presence of a psychomotor block.

Special Examinations. In a number of patients reflex dilatation by means of body warming was carried out. In all but 2 the rate of rise in skin temperature was parallel in the affected and in the normal extremity. In the 2 exceptions a lag was noted in the injured limb. In all instances, however, there was no difference in the ultimate temperature elevation in the injured extremity as contrasted with the normal one, despite lower initial controlled skin temperature readings in the involved limb.

In several patients the reactive hyperemia test was performed. Results in the affected limb were uniformly normal, except in one patient in whom there was a delay in the appearance of the flush.

Records of roentgenologic examination of the hands or feet made prior to admittance to Mayo General Hospital were available in 51 of the 142 patients. In 42 there was evidence of generalized or spotty osteoporosis. The change was minimal in 6, moderate in 28, and marked in 8. In the other 9 no abnormalities were observed on the roentgenograms.

THERAPY

The treatment given the 142 patients with post-traumatic vasomotor disorders at the vascular center of Mayo General Hospital can be divided into

four categories, namely, active exercise and physical therapy, neuropsychiatric measures, lumbar sympathetic block, and lumbar sympathectomy. As a matter of convenience, the treatment of osteoporosis will be considered separately. It is recognized that these divisions are somewhat arbitrary and overlapping.

For example, whether or not a neuropsychiatric disorder was present, and regardless of whether expert psychiatric treatment was required, it was felt necessary to gain the confidence of the patient and to impress upon him both the necessity for his active cooperation and the favorable outcome that might be expected if he cooperated. Such instructions and suggestions on the part of the attending physician constituted, in reality, psychiatric treatment. Again, no matter what other type of therapy was carried out, active use of the involved extremity was part of the routine. It was learned early in the management of these patients that little could be accomplished by psychiatric interviews, sympathetic blocks, or sympathectomy unless the patient was repeatedly urged to take advantage of any resulting improvement in his condition by following up the gain with persistent use of the affected limb. It was only in this manner that atrophy, weakness, stiffness, and improper stance or gait could ultimately be corrected.

Active Exercise and Physical Therapy

In 95 of the 142 patients, active use of the involved extremity supplemented by physical therapy constituted the chief treatment employed. When the patients were first seen the importance of activity was pointed out and explained to them in terms which they could readily understand. The role that disuse was playing in their condition was stressed and it was emphasized that a vicious cycle had been set up which would result in continued difficulty as long as inactivity persisted.

In those individuals who had demonstrable edema of a lower extremity, an attempt was made to bring the swelling under control before anything else was done. These patients were put to bed with the extremity elevated until all swelling had disappeared. If edema recurred on activity, an elastic support was used together with periods of bed rest with the limb elevated. Careful observation of the patient made it possible to permit activity to a degree slightly less than that at which edema reappeared. The use of the elastic support was continued until swelling was no longer present on dependency.

If a patient was confined to bed on his admittance to the hospital, the therapeutic program was aimed at making him ambulatory as rapidly as circumstances permitted. A short period of ambulation with crutches and then with a cane was sometimes necessary before unaided walking was accomplished. Widespread petechial hemorrhages sometimes appeared in the skin of the affected extremity when a patient first began to walk after a prolonged period of immobilization of the limb. They usually cleared up promptly as activity

increased. Patients who were admitted using crutches or canes were persuaded to discard them immediately. Since all patients who had been bedridden or who had been using aids usually showed timidity and favored the affected limb when they first began to walk, careful attention was paid early in the reconditioning program to the acquisition of a normal stance or gait. It was not always easy to accomplish this, partly because pain was frequently associated with early movement (though it tended to decrease as the men became more active) and partly because most tended to estimate their improvement by the distance they could cover rather than by the correctness of their gait. They were made to understand, however, that more benefit was derived from walking a short distance properly than a long distance improperly. Emphasis was placed on the fact that only when a correct gait was employed would all the muscles be brought into play and strengthening and improvement in tone accomplished.

In addition to the active use of the affected limb which was the principal type of physical therapy utilized, substantial benefit was usually obtained through gentle massage and directed active and resisted exercise of all the weak muscles. Passive exercises and manipulations were found to be of little help. Whirlpool baths were used on some of the first patients to be treated, but in general no improvement was observed following their use and so they were omitted. It was necessary to emphasize to all of the patients that they could accomplish much more by voluntary exercise at frequent intervals throughout the day than by sole reliance on the relatively short period of treatment supervised by the physical therapist.

The same principles of treatment were employed for the upper and for the lower extremities.

Results. As improvement appeared, the patients usually underwent a change in attitude and became decidedly more optimistic concerning the outcome of their disability. Concomitantly with their altered state of mind, they seemed to pursue the program more vigorously and to improve more rapidly. As a result, edema diminished and gait became relatively normal. If discomfort persisted it was less severe and appeared only after the patient had walked for distances varying from 1 to 3 or more miles. Along with this improvement there were observed an increase in muscle power and an alleviation of the vasomotor disturbances. Almost invariably limbs which had been cold, wet, and cyanotic when first seen, gradually became warmer, dryer, and of better color.

In 50 of the 95 patients in whom active exercise and physical therapy were the chief methods of treatment, results were satisfactory. Five of the remaining patients were under observation for too brief a time to permit final evaluation of results. In the other 40, few, if any, beneficial effects were noted. It should be emphasized again that in some respects many of the patients analyzed under other methods of treatment also represent failures with active exercise and

physical therapy, since these measures were employed adequately in all but a few patients prior to the institution of other methods.

One patient may be considered as typical of those in whom active exercise and physical therapy produced successful results:

Case Report

When this patient entered the Mayo General Hospital he was unable to use his fingers and complained of marked edema, pain, coldness, and hyperhidrosis of the right hand. The bones of the right forearm had been fractured on several occasions prior to the onset of symptoms. When the hand was first examined all of the fingers were edematous and stiff (Fig. 54A). He was given an ordinary surgical glove to wear and encouraged to use the fingers as much as possible. At the same time, an intensive course of physical therapy was instituted. Part of this called for the patient to squeeze a soft rubber ball. This he did during most of the day. At the end of 14 days, edema had completely disappeared and he could move the fingers of the right hand almost as well as those of the left (Fig. 54B).



Figure 54. A. Massive edema of right hand in patient with vasomotor disorder following trauma. B. Disappearance of edema several weeks after institution of intensive active exercise and physical therapy.

Disposition. By the time the patients in this group were ready for disposition those who had demonstrated a satisfactory response to therapy were either free of residual vasomotor signs and symptoms or whatever manifestations persisted were minimal. In some the rather generalized increase in vascular tonus previously present had tended to decrease as the affected limb was restored to a more normal state. Even when patients were not completely recovered, however, it was felt that further hospitalization for the vasomotor condition was unnecessary—and might be actually harmful—since there was every reason to believe that symptoms and signs would become less and less apparent with continued physical activity and the passage of time.

Twenty-nine of the 95 patients in this group were therefore transferred to various other sections of the hospital for the correction of other medical or surgical conditions, 14 were sent to convalescent facilities for advanced re-

conditioning, 5 were discharged directly to duty, and the remainder were separated from the service.

Neuropsychiatric Measures

Standard neuropsychiatric measures were used in 9 of the 11 patients in this group. In 8, treatment was carried out by the psychiatrist. In the ninth patient it was carried out by the ward officer under the direction of the psychiatrist. The routine usually included suggestive therapy under sodium amytal narcosis or hypnosis. Careful, concerted efforts were always made to give the patient insight into his condition and to make him understand that he had no organic disorder which would prevent his recovery if he would continue to push himself to the limit in the active use of the affected limb.

In the 2 remaining patients psychiatric measures were not regarded as necessary. In 1 of these the psychiatrist thought that the complaints of cyanosis, coldness, swelling, and pain in the foot on weight-bearing were largely psychosomatic, but they cleared up so satisfactorily under ordinary physical activity that psychiatric measures were not invoked. When this patient was transferred to a convalescent hospital for advanced reconditioning his only complaint was aching in the affected foot after he had walked for a distance of 3 miles. The other patient made fair progress with active exercise of the affected upper extremity until improvement reached a plateau; he was left with some residual cyanosis, increased sweating, and weakness.

Results. The results of psychiatric treatment in the 9 patients treated were classified as good in 4, poor in 4, and fair in 1.

Two patients in whom no improvement was observed after psychiatric measures were transferred to a neuropsychiatric center for more intensive therapy. One of them (Case 8, Table 49) had complained of swelling, hyperhidrosis, and cyanosis of the foot following a compound fracture of the proximal phalanx of a toe, the result of an accidentally self-inflicted wound 9 months prior to admittance. His symptoms did not improve with activity but there was some reduction in swelling following lumbar sympathectomy. Initial progress was excellent but after he returned from a convalescent furlough he still had some swelling and weakness of the foot. The psychiatrist was of the opinion that definite hysteria was present, since improved strength in the foot and more normal walking could be demonstrated under hypnosis. Several subsequent treatments were given but the final result was poor.

The second patient transferred to a neuropsychiatric center for further treatment had also been admitted with swelling, cyanosis, weakness, and pain in the foot on weight-bearing. He had improved considerably with active exercise and physical and occupational therapy but following a convalescent furlough complained of increased weakness and pain and, in addition, of nervousness, anorexia, and insomnia. He had also developed a tremor and some weakness in one of his hands. The psychiatrist felt that this man was suffering

TABLE 49. SYMPATHECTOMY IN POST-TRAUMATIC VASOMOTOR DISORDERS

[Indication: Persistent Edema]

Case No.	Operation, months after injury	Original injury	Manifestations	Results
1	4.0	Compound fracture, tibia and fibula.	Massive edema, leg. Ununited fracture, cyanosis, small ulcer. (Attempt at bone graft abandoned because of edema.)	Edema considerably reduced. Foot warm, dry, well colored. Successful bone graft.
2	8.0	Simple fracture, 2d and 3d metatarsals and cuneiform.	Marked edema, foot and leg, persisting with bed rest. Cyanosis, coldness, hyperhidrosis, stocking hypesthesia. Pain on weight-bearing requiring crutches.	Edema largely disappeared. Foot warm, dry, well colored. Pain only after walking 2 miles or more. Hypesthesia decreased.
3	11.0	Foot crushed.....	Massive edema, foot and leg, persisting with bed rest, elevation, and typhoid vaccine. Coldness, hyperhidrosis, hypesthesia, motor paralysis. Pain on weight-bearing. (Conversion hysteria, unaffected by psychotherapy.)	Reduction of 1 in. in circumference of foot, and 1½ in. in circumference of leg within 2 days. Edema largely subsided. Foot warm, dry. Hypesthesia slightly decreased. Could walk with cane fairly well.
4	5.0	Soft tissue wound, foot.	Massive edema, foot and leg, persisting with bed rest, elevation and long courses of penicillin and sulfadiazine. Moderate rest pain. Severe local infection with increased local heat.	Reduction of 1½ in. in circumference of foot and 4½ in. in circumference of leg within 36 hours. Edema disappeared but subsequently recurred with flareup of infection, again to disappear with elevation. Pain disappeared, ulcer healed. Walks well.
5	Unknown	Compound fracture, tibia and fibula.	Massive edema ankle, severe osteomyelitis.	Edema slightly lessened. Outcome unsettled.
6	5.5	Foot crushed.....	Massive edema, foot and ankle, persisting to moderate degree with bed rest. Coldness, hyperhidrosis, cyanosis, and hypesthesia of foot. Marked paresis. Atrophy. Pain on weight-bearing. Patient bedridden.	Marked improvement. Edema gone except slight after long standing. Sensation normal. Strength much improved. Foot warm, dry, well colored. Slight pain after walking 1 mile.
7	4.5	Soft tissue wound, lower extremity.	Marked edema, foot and ankle. Pain on weight-bearing requiring cane. Cyanosis. Affected foot warmer and oscillometry better than normal foot. Weakness and atrophy. Tibial nerve paralysis.	Steady improvement, final disappearance of symptoms.
8	9.0	Compound fracture, phalanx.	Moderate edema. Pain on weight-bearing, causing a limp. Cyanosis, hyperhidrosis. Weakness. (Patient subsequently found to have hysteria)	Little improvement. Swelling and limp still present. Foot warm and dry.

from an anxiety state and when no improvement was secured with sodium amytal narcosis and other treatment, recommended his transfer to another hospital.

In a third patient in whom an unsatisfactory result was obtained with neuropsychiatric measures, definite evidence of conversion hysteria was present but considerable, though incomplete, improvement occurred after sympathectomy (Case 3, Table 49).

Of the 4 patients in whom the results were classified as good 2 are of interest:

Case Reports

The first was a patient who was admitted to the vascular center of Mayo General Hospital 4 months after an injury to the right leg. He received this injury when he was kicked during a football game. He gave a history of previous trauma to the same limb 1 year earlier, followed by pain, swelling, and cyanosis which decreased slowly and finally disappeared. Within a few days after the recent injury the return of these same symptoms and signs were noticed. They increased in severity and eventually he could walk only on crutches. A series of 10 sympathetic blocks resulted in transient improvement in the strength of the affected foot. When examined it was immediately evident that he was unwilling to do very much for himself. He appeared apprehensive and was rather jumpy while being questioned. There was marked paresis of all the movements of the foot and ankle but efforts were associated with tremor and with tonic contractions of the antagonistic muscles.

The psychiatrist felt that this patient had hysteria and treated him with suggestive therapy under sodium amytal narcosis. During this procedure the affected foot, which had been cold, wet, and extremely cyanotic, became warm, dry, and of good color. The patient could move it freely and strongly through a full range of motion. He was made to walk and did so with a practically normal gait. After this single treatment, which was followed by careful and full explanations regarding the nature of his condition and progress, he improved daily. When he was discharged after being hospitalized for a month, the foot was normal in color and warmth, edema was no longer present, and there was only a slight reduction in motor power. The range of motion was normal. He experienced no pain until he had walked a mile and a half. There was, however, no improvement in the moderate osteoporosis present on admittance.

The second patient was admitted to the hospital 4 months after he had sustained injuries of the soft tissue of the left thigh and leg from a shell fragment. The injury had been followed by immediate paralysis and numbness of the foot but flexion and sensation on the sole had returned at the end of 6 weeks. At the time of admittance he complained of swelling, cyanosis, coldness, and sweating of the left foot, with tingling and aching pain on attempted weight-bearing. He walked with crutches. Examination of the left foot showed cyanosis, a reduction in skin temperature, moderate hyperhidrosis, paralytic limitations of eversion, and complete loss of extension of the affected foot and toes. There was some hypesthesia of the foot, with anesthesia in the distribution of the saphenous and the lateral sural nerves.

The neurosurgeon had no doubt that the patient had a sciatic nerve injury with partial peroneal paralysis. Efforts at active use of the limb with a foot-drop brace were futile, and since a fairly good response was obtained with sympathetic block, a lumbar sympathectomy was performed (Case 10, Table 50). There was considerable improvement following this procedure and weight-bearing was possible with the use of crutches; at the end of a week he discarded these for a cane. The foot was now warm and dry, and there was only minimal edema in the leg and none in the foot. There was also less pain on walking.

TABLE 50. SYMPATHECTOMY IN POST-TRAUMATIC VASOMOTOR DISORDERS

[Indication: Pain on Weight-Bearing or Rest Pain]

Case No.	Operation, months after injury	Original injury	Manifestations	Results
9	5.0	Foot crushed.....	Pain on weight-bearing requiring crutches. Marked coldness, cyanosis, hypesthesia, moderate edema. Atrophy, calf.	Walks without limp, pain only slight after prolonged walking. Foot warm, dry, well colored.
10	7.0	Soft tissue wound, thigh.	Pain on weight-bearing requiring crutches. Coldness, cyanosis, hyperhidrosis, slight edema. Apparent peroneal palsy. Atrophy, calf.	Pain decreased. Walks with cane. Foot warm, dry, well colored. Subsequently found to have hysteria. Complete cure, including motor and sensory return, after single amytal narcosis.
11	9.0	Periostitis, tibia.....	Pain on weight-bearing requiring crutches. Coldness, cyanosis, hyperhidrosis. Atrophy, calf.	Complete relief.
12	7.0	Soft tissue wound, foot.	Pain on weight-bearing requiring crutches. Moderate edema, cyanosis, weakness, and atrophy, calf.	Moderate improvement on weight-bearing. Walks without cane but limps. Some pain persistent. Foot warm and dry. Edema less.
13	7.0	Soft tissue wound, foot.	Pain on weight-bearing requiring crutches. Coldness, cyanosis, slight edema. Atrophy, calf.	Much improvement. Pain only after walking 2 miles or more. Foot warm, dry, well colored. Edema first reduced, then disappeared.
14	9.5	Simple fracture, metatarsal.	Pain on weight-bearing causing limp. Slight edema, cyanosis, weakness, coldness, atrophy.	Much improvement. Pain only after walking 1 mile. Edema less. Foot warm and dry. Foot stronger.
15	6.5	Chip fracture, second and third phalanges.	Pain on weight-bearing requiring cane. Slight edema, cyanosis, weakness.	Steady improvement, then complete relief.
16	6.0	Soft tissue wound, foot.	Pain on weight-bearing. Moderate edema, cyanosis, reduced oscillometry. Atrophy and weakness.	Much improved. No discomfort until after walking more than 1 mile. No edema. Foot warm and well colored.
17	7.5	Soft tissue wound, foot.	Pain on weight-bearing causing limp. Marked coldness, cyanosis, hyperhidrosis. Weakness and atrophy.	Marked improvement. No discomfort until after walking more than 1½ miles. Foot warm, dry, well colored.
18	6.0	Foot crushed.....	Pain on weight-bearing requiring cane. Slight edema, coldness, cyanosis, hyperhidrosis. Weakness, atrophy, hypesthesia.	Much improved. Able to walk 3 or 4 miles without pain. Foot warm, dry, well colored. Still slight edema. Foot stronger. Sensation normal.

TABLE 50. SYMPATHECTOMY IN POST-TRAUMATIC VASOMOTOR DISORDERS—Continued
[Indication: Pain on Weight-Bearing or Rest Pain]—Continued

Case No.	Operation, months after injury	Original injury	Manifestations	Results
19	9.0	Compound fracture, lower leg.	Moderate burning rest pain, increased with dependency. Moderate edema, cyanosis, coldness.	Much improved. Pain much less. Edema less. Foot warm. Slight cyanosis in dependency.
20	Unknown.	Simple fracture.....	Moderate burning pain at rest, cyanosis, coldness. Partial peroneal palsy.	Much improved. Pain much less. Foot warm, dry, well colored.

Two months later the sciatic nerve was explored and found to respond well to faradic stimulation. A week after the operation psychiatric consultation established a diagnosis of hysteria. As the result of a single interview under sodium amytal narcosis the patient regained all movements, had return of sensation, and walked unaided normally and without pain.

This case illustrates most emphatically the necessity of bearing in mind the possible psychiatric basis of post-traumatic vasomotor complaints and of instituting appropriate psychiatric therapy before attempting other, more heroic procedures.

Disposition. Except for the 2 soldiers transferred to neuropsychiatric centers for further treatment, all the patients in the group treated by neuropsychiatric measures were separated from the service even though some of them showed marked improvement in, or even recovery from, the vasomotor disorders for which they had been hospitalized.

Sympathetic Block

Thirty-two patients received sympathetic blocks prior to their admittance to Mayo General Hospital; the procedure was carried out on an average of 6 months after the onset of the disorder, with a range of from 1 to 22 months. From 1 to 28 blocks had been given to each individual.

Sympathetic blocks were carried out in a number of the patients with post-traumatic vasomotor disorders after they were received at the Mayo General Hospital, but in only 7 instances was the method employed as a therapeutic measure. In the remaining patients the blocks were carried out as a test procedure to determine the advisability of sympathectomy.

Results. An analysis of the medical records, supplemented by questioning the patients, made it appear that 12 of the 32 patients who received sympathetic block prior to their arrival at the Mayo General Hospital had noticed no subsequent change in their condition other than some temporary elimination of coldness, cyanosis, and sweating during the period of anesthesia. In 13 patients there appeared to be definite though transient benefits from the procedure. In 4 patients there was evidence of slight or moderate permanent improvement, and in 3 patients good permanent results were obtained.

In evaluating the sympathetic blocks performed before the patients were seen at the Mayo General Hospital, it was apparent that in a few instances effective anesthesia of the sympathetics had not been obtained. This was evidenced by the fact that the limb remained cold and wet following the injection. In others the possible therapeutic effect upon walking was compromised by associated inadvertent blocking of the somatic nerves, with resulting temporary anesthesia and paralysis, which prevented the use of the lower extremities during the period of the effective sympathetic block. Furthermore, it was apparent that in most of the patients no effort had been made to make the patient walk or otherwise actively exercise his affected limb immediately after the injection. In only a few of the patients was advantage taken of the improvement by insistence upon progressively increased use of the limb and it was in this group that some benefit over a period of hours or days was noted following the procedure. There is no question that if sympathetic blocks are to achieve maximum benefit, the involved extremity must be subjected to weight-bearing and walking or other active exercise immediately after the injection, and that activity must be continued to the point of tolerance. Only when such a plan is employed can the effectiveness of the procedure properly be evaluated.

Two of the 7 patients in whom sympathetic blocks were employed as a therapeutic measure after they reached the Mayo General Hospital had syndromes characterized by coldness, hyperhidrosis, and weakness of the hand. Another had rather marked edema of the hand without any other significant change. The remaining 4 patients complained of edema, coldness, cyanosis, and hyperhidrosis of the injured foot. Treatment was instituted from 6 to 12 months following injury. Three patients received only a single sympathetic injection while 4 had 2 treatments each. In every instance there was definite, steady improvement following the blocks, manifested by marked diminution in coldness, hyperhidrosis, and edema, return of good color, also increase in motor power and function. Each of these patients had previously been making earnest efforts to use the extremity actively and to the best of his ability but without apparent improvement. From the sequence of events there was little doubt that the block rather than other therapeutic efforts was primarily responsible for the altered clinical picture. It is of interest that pain was not a prominent complaint in any of the patients who experienced lasting improvement as a result of sympathetic block.

Sympathectomy

Sympathectomy was the principal method of treatment in 34 patients, in 1 of whom the operation was performed twice. Three of these patients have already been mentioned in the neuropsychiatric category but are again analyzed under this heading for the sake of completeness.

In all in whom the lower extremity was involved, lumbar sympathectomy was carried out under spinal anesthesia through an anterior extraperitoneal

approach; the second and third lumbar sympathetic ganglia, with the intervening chain, were excised. Sympathectomy of the upper extremity was performed through a posterior muscle-splitting incision with resection of a portion of the third rib and of the transverse process. The second and third thoracic ganglia were decentralized; the chain was severed between the third and fourth ganglia and the isolated segment encased in a silk cylinder. Intradural section of the second and third anterior nerve roots and extradural section of the corresponding posterior roots were steps in the procedure. There were no deaths and no complications in any of these patients.

Decision to perform sympathectomy was made on the basis of a number of factors. In patients with ulcers, it rested primarily upon the chronicity of these lesions and the presence of associated vasospasm. In patients with evidence of excessive sympathetic activity, sympathetic procaine anesthesia proved a reliable test for judging results which would follow sympathectomy. In those with edema, preliminary testing with procaine block was not a reliable indication of the effects to be expected of sympathectomy. In a very few, a demonstrable transient diminution in swelling occurred, but in a number of others it was necessary to determine whether the increase in the size of the extremity which occurred during an hour of walking immediately following the injection was less than that observed during a comparable interval on another occasion. If it was thought to be less following the injection, then sympathectomy was resorted to. In most patients with edema, however, no really convincing evidence concerning the result to be anticipated from sympathectomy could be derived from a preliminary sympathetic block. In spite of the indefinite results of preliminary testing, the therapeutic effect of sympathectomy was frequently extremely satisfactory.

In patients with pain, results of preliminary testing with sympathetic procaine anesthesia were also so variable as to be considered unreliable. Following the injection some patients were surprised to find that they could move the affected part freely through a wide range of motion without any discomfort and that they could walk or otherwise exercise either with no pain or with much less discomfort than previously experienced. In such instances it was felt that sound evidence existed that sympathectomy would be effective. In others, however, sympathetic anesthesia had no beneficial effect upon the pain associated with exercise, yet in these good results frequently followed sympathectomy.

Results. To simplify the analysis, patients upon whom sympathectomy was performed have been divided into 4 groups, namely, those with considerable persistent edema, those with pain on walking, those with excessive sympathetic activity, and those with chronic ulceration of the skin. This division is somewhat arbitrary since symptoms and signs were seldom limited to any one of the categories mentioned. Some of the patients with edema, for example, had pain also on weight-bearing and presented evidence of vasoconstriction, while

those whose chief complaint was pain on weight-bearing likewise presented excessive vasomotor tonus, often associated with slight or moderate edema. Similarly, patients with chronic ulceration gave evidence of increased vasomotor activity and suffered from edema and discomfort on walking. Nonetheless, this division serves a useful purpose in presenting the information in a more concise fashion and selection has been made according to the primary indication for operation.

In 7 of the 8 patients upon whom sympathectomy was performed primarily because of persistent edema (Table 49), the procedure was carried out on an average of about 7 months after injury, the range being 4 to 11 months. In 1 patient edema was only moderate, in 2 it was marked, in the 5 remaining it was massive. All of these had had a trial of bed rest, with elevation of the affected limb, and later, when they became ambulatory, of elastic support. In 6 of the 8 patients edema persisted with bed rest alone, and in 4 of these 6 it did not subside even after a prolonged period of elevation. Six patients had evidence of vasospasm and 1, in whom infection was present, also had definite local hyperemia (Case 4).

In 1 of the patients in this group (Case 1) in whom edema was associated with an ununited fracture of the tibia, exploration was undertaken with the idea of performing a bone graft, but the procedure had to be abandoned because of the marked waterlogging of all the tissues. There was considerable reduction in the edema following sympathectomy and when the bone graft was subsequently undertaken, the surgeon estimated that the condition had improved by about 90 percent. In another patient, however, in whom massive edema was associated with a compound fracture and osteomyelitis of the ankle (Case 5), only slight improvement followed sympathectomy.

One case from this group is of special interest:

Case Report

This patient, with massive edema (Case 4), had sustained a soft-tissue injury of the left foot from a shell fragment. The foot and leg were enormously swollen and local infection was present (Fig. 55A) associated with fever and weight loss. Intensive treatment consisting of repeated debridement, repeated incision and drainage, and sulfonamide and penicillin therapy over a long period, with immobilization and elevation of the limb, had produced no improvement whatsoever. A sympathetic block produced no demonstrable diminution of the edema but pain was transiently diminished. Sympathectomy was performed 5 months after the injury. Within 36 hours the circumference of the foot had been reduced by $1\frac{1}{2}$ inches, that of the leg by $4\frac{1}{2}$ inches. Over the next few days the edema disappeared completely, as did the infection, and healing occurred with only a tiny ulcer remaining. Subsequent recurrence of the infection, with transient recurrence of edema, responded well to elevation and rest. Following this episode the wound healed completely (Fig. 55B), edema disappeared entirely, and the patient could walk normally and with comfort.

The other 5 patients in the group upon whom sympathectomy was performed for persistent edema presented other signs and symptoms more commonly seen following injury. Four were unable to bear weight properly be-

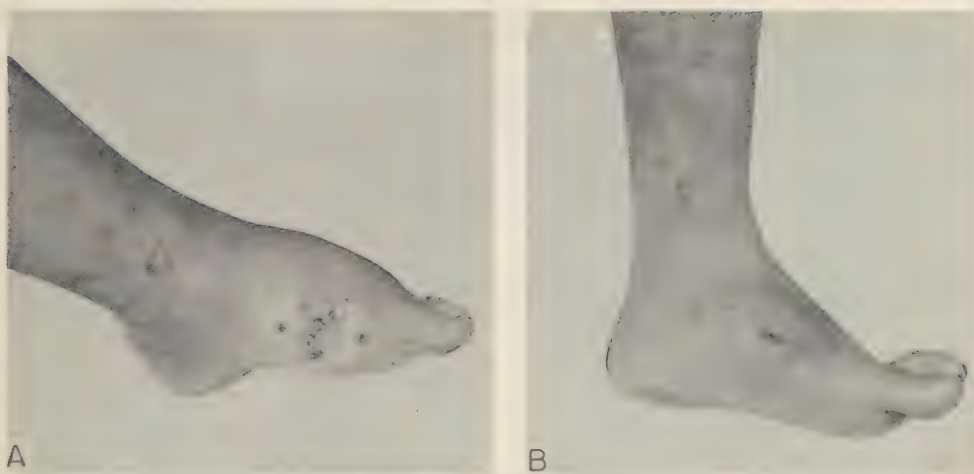


Figure 55. A. Massive edema and ulceration of left foot and lower leg in patient with post-traumatic vasomotor disorder and resistant infection. No improvement followed continued bed rest, elevation of the extremity, and sulfonamide and penicillin therapy. B. Healing of ulcer and disappearance of edema after lumbar sympathectomy.

cause of pain, the fifth walked with a decided limp. All complained of weakness, 1 had a virtual paralysis, and 3 had hypesthesia. Three of the 5 had signs of intense sympathetic hypertonus with coldness and hyperhidrosis. The fourth had persistent hyperhidrosis and cyanosis. The fifth had a cool foot which, however, was warmer than the contralateral limb. By means of an oscillograph it was determined that the volume flow of blood to the injured extremity was greater than that to the uninjured one. In 3 of these 5 patients (Cases 2, 6, and 7) there was either partial or complete subsidence of edema following sympathectomy. All could walk better, without discomfort and for longer distances, than before operation. Hypesthesia was improved or was no longer present. In 1 patient (Case 7), who was hospitalized sufficiently long for conclusions to be warranted, there was no recurrence of edema during the period of observation.

The other 2 patients upon whom sympathectomy was performed for persistent edema have been discussed previously under the heading of neuropsychiatric therapy. One, who had transient improvement in edema following sympathectomy (Case 8, Table 49), was eventually found to have a conversion hysteria which responded poorly to psychotherapy. The history of the second patient (Case 3) is instructive because it illustrates the therapeutic effect of sympathectomy in an hysterical individual who also showed poor response to psychotherapy:

Case Report

Following a crushing injury of the left foot, this patient had marked swelling, coldness, hyperhidrosis, and hypesthesia (Fig. 56A). Paralysis was almost complete. No improvement was observed following psychiatric interviews and no benefit other than transient



Figure 56. A. Edema of left foot in patient with post-traumatic vasomotor disorder and hysteria 11 months after injury. This picture was taken after 3 weeks of continuous bed rest with elevation of the extremity. Response to psychotherapy was poor. B. Appearance of foot 10 days after lumbar sympathectomy. Note almost complete disappearance of edema.

warmth and dryness of the foot followed sympathetic block. Sympathectomy was performed 11 months after the original injury. Within 48 hours after operation the edema, which had persisted with bed rest and elevation, practically disappeared. The patient, although he walked with a limp and required a foot-drop brace and a cane, was converted from a bed-ridden to an ambulatory patient (Fig. 56B) during this brief period. Further psychotherapy was of no value and, since a plateau of improvement had been reached, he was separated from service.

Sympathectomy was performed in 10 patients who complained of pain on weight-bearing and in 2 who had pain at rest (Table 50). At the time of operation 1 was confined to bed and refused to walk, 5 walked with crutches, and 2 with canes. The other 4 walked with a limp and favored the injured limb. In 9 of the 12 there was positive evidence of vasospasm and 9 had slight or moderate edema. Cyanosis was present in all 12.

One of the patients who had moderate improvement after sympathectomy has already been mentioned (Case 10). He was subsequently found to have hysteria and a complete cure occurred after a single interview under sodium amytal narcosis.

In the remaining patients results varied from good to excellent. Some were able to walk several miles before the onset of discomfort while others had no residual pain at all. Both patients who had complained of rest pain showed considerable improvement. In every instance edema either disappeared or was

present only to a slight degree, even after prolonged dependency. All patients now had warm, dry feet and only one showed residual cyanosis. Muscle strength also improved in every instance. By the time the patients left the hospital, there was an increase in the size of the muscles even if definite atrophy had previously existed.

It is important to emphasize that in this group, except for 1 or 2 patients treated early in the experience, all had been subjected to a rigid regimen of active exercise prior to operation without definite relief from symptoms. Even the few who followed no planned program of calisthenics had been encouraged to walk and to exercise the affected limb.

On the indication of excessive-sympathetic activity (Table 51), 13 operations were performed on 12 patients. Eight of the procedures were dorsal and

TABLE 51. SYMPATHECTOMY IN POST-TRAUMATIC VASOMOTOR DISORDERS
[Indication: Excessive Sympathetic Activity]

Case No.	Operation, months after injury	Original injury	Manifestations	Results
21	8.0	Soft tissue wound, calf....	Marked coldness, entire foot and leg. Cyanosis, hyperhidrosis, moderate edema. Heel cord contracture, stiffness, and weakness, foot and toes.	Foot warm, dry, well colored. No lessening of or weakness, and stiffness persisted. Subsequently tendo Achillis lengthening. Useful foot.
22	6.5	Compound fracture, astragalus and navicular; division, extensor tendons.	Marked coldness, hyperhidrosis, cyanosis. Slight edema, long, deep transverse scar, dorsum foot.	Foot warm, dry, comfortable. Subsequent tendon repair only partly successful. Good wound healing.
23	9.5	Compound fracture, femur	Marked coldness, hyperhidrosis, cyanosis. Moderate edema.	Complete relief.
24	22.0	Cellulitis, lower extremity.	Marked coldness, cyanosis, hyperhidrosis, and epidermophytosis. Pain on weight-bearing, limp: Weakness, slight edema, hypesthesia.	Much improved. Foot warm, dry, well colored. No epidermophytosis, no edema. Hypesthesia improved. No pain. Still some weakness.
25	12.0	Sprain, lower extremity...	Coldness, cyanosis, hyperhidrosis. Cold sensitivity. Slight swelling and stiffness on walking. Weakness.	Much improved. Foot warm, dry, well colored. No cold sensitivity. Little or no discomfort on walking. Still some weakness.
26	9.0	Compound comminuted fracture, phalanges 4 and 5. Laceration flexor tendons.	Hyperhidrosis. Marked cold sensitivity. Cyanotic rubor.	Complete relief. Subsequent tendon repair.
27	9.0	Traumatic amputation, 3d finger.	Coldness, hyperhidrosis, weakness. Phantom-limb pain.	Complete relief. No pain. Warm, dry hand. Strength largely regained.

TABLE 51. SYMPATHECTOMY IN POST-TRAUMATIC VASOMOTOR DISORDERS—Continued

[Indication: Excessive Sympathetic Activity]—Continued

Case No.	Operation, months after injury	Original injury	Manifestations	Results
28	8.0	Soft-tissue wound, arm. Median nerve palsy.	Coldness, cyanosis, hyperhidrosis. Some burning. Cold sensitivity.	Marked relief.
29	8.5	Compound fracture, 5th metacarpal. Ulnar nerve palsy.	Coldness, cyanosis, hyperhidrosis.	Complete relief.
30	15.0	Compound comminuted fracture, humerus. Median and ulnar nerve palsy.	Coldness, cyanosis, cold sensitivity, hyperhidrosis of thumb.	Complete relief.
31	9.0	Laceration, flexor tendons 2, 3, 4. Amputation 5th finger.	Coldness, cyanosis, hyperhidrosis. Cold sensitivity. Weakness.	Complete relief.
32	11.0	Compound comminuted fracture, left ulna. Ulnar nerve paralysis.	Cold sensitivity. Coldness, cyanosis, aching, throbbing, and stiffness on exposure. Hyperhidrosis.	Complete relief.

5 were lumbar sympathectomies. Ten of the 12 patients in this group complained before operation of excessive coldness, generally associated with both cyanosis and hyperhidrosis, at ordinary environmental temperatures. Six had cold sensitivity manifested by marked coldness, stiffness, and discomfort on exposure to a low temperature. The 5 with involvement of the lower extremity all had slight or moderate edema and 1 had also pain on weight-bearing. One (Case 27), who had had an amputation of a finger, had moderate phantom-limb symptoms.

Following operation, 7 patients had complete relief and the other 5 were very much improved. Cold sensitivity was diminished in each patient in whom it had been present. The limbs were dry, warm, and well colored following operation. Hypesthesia, which had been present in 1 (Case 24), was considerably improved. Corrective operative procedures upon the affected limbs in 2 (Cases 21 and 22) were followed by prompt healing of the wounds.

In 2 patients (Table 52) operation was performed chiefly because of the persistence of chronic ulcers. In both, although repeated efforts at skin grafting had failed, healing occurred fairly promptly after sympathectomy. In 1 (Case 34) it was apparent before sympathectomy was performed that transfer of full thickness skin would eventually be required, but it was thought that the chance of success would be enhanced if this could be done after epithelization of the ulcer and correction of the vasospastic disorder. In 3 other patients chronic ulcers healed satisfactorily with rest and saline compresses, without sympathectomy.

TABLE 52. SYMPATHECTOMY IN POST-TRAUMATIC VASOMOTOR DISORDERS

[Indication: Chronic Ulcers]

Case No.	Operation, months after injury	Original injury	Manifestations	Results
33	21.0	Simple fracture, tibia and fibula, evulsion of skin. Ulcer 2 by 2 cm. over internal malleolus.	Pain on weight-bearing; edema, cyanosis and reduced oscillogmetry. Foot cool but warmer than normal extremity.	Split, sliding, full thickness and pedicle grafts failed before sympathectomy. After sympathectomy ulcer healed rapidly and permanently. Foot warm, dry, of good color. Edema much less. Walking improved.
34	12.0	Compound fracture, fibula. Ulcer 4 by 3¼ cm. on lateral surface leg.	Aching rest pain; pain on weight-bearing; edema, cyanosis, coldness and hypesthesia.	Small deep and split grafts failed before sympathectomy. After sympathectomy ulcer healed rapidly, transfer graft successful. Foot warm, dry, well colored. Hypesthesia gone. Edema less. No pain on weight-bearing.

In all patients treated by sympathectomy, strenuous active exercises were insisted upon after a short period of convalescence. It was the universal experience that such activity could be undertaken with little or no discomfort after the operation and that steady subsequent improvement would occur as the patient continued to take advantage of his increased ability to perform physical exercise.

Except for one patient transferred to a neuropsychiatric center (Case 8, Table 49), a second discharged because of hysteria (Case 3, Table 49), and a third separated because of marked pes planus (Case 21, Table 51), all those treated by sympathectomy in whom no further surgery was necessary for correction of other combat-incurred defects were transferred to convalescent facilities for advanced reconditioning or return to duty.

Effect of Treatment Upon Osteoporosis

Comparative roentgenograms of patients with osteoporosis made at the time of admittance to the hospital and some months later after institution of treatment were available for study in 24 cases. In 11 of the patients no alteration in the degree of osteoporosis was noted in the final roentgenograms. In this group the first film, taken between 3 to 14 months after the original trauma (an average of about 9 months), showed slight osteoporosis in 2, moderate bone changes in 8, and marked changes in 1. Final roentgenograms were obtained from 4 to 17 months after injury, with an average of about 11 months. Average time interval of observation was thus about 2 months.

The other 13 patients showed definite improvement in respect to osteoporosis in the films taken after treatment. The original films were taken from 2.5 to 6 months after trauma with an average of about 5 months. These first

films, revealing a reversal toward the normal state, were obtained from 5 to 12 months after injury. There was an average, then, of about 4 months between the original films and the films which indicated improvement. The original roentgenograms showed slight osteoporosis in 1 patient, moderate bone changes in 6, and marked changes in 6. Of the 6 patients who originally showed marked changes, 1 showed normal structure in the final film and 4 showed only moderate osteoporosis. In the remaining patient the films revealed only slight improvement. In 3 of 6 patients who originally had moderate osteoporosis, evidence of only mild involvement was present after treatment; in the other 3 the roentgenograms revealed a normal or practically normal condition. The single patient who originally had slight osteoporosis had normal appearing bones on the last examination.

In analyzing the roentgenologic changes in osteoporosis from the standpoint of treatment employed in these patients, it is of interest that 4 out of 9 patients treated by exercise, physical therapy, or psychotherapy, and 9 of 15 patients treated by sympathectomy, showed some improvement. Two other patients treated by sympathectomy, in whom no change in the degree of osteoporosis was observed after treatment, had fractures of the long bones which had required prolonged immobilization before operation, and it is possible that the factor of continued disuse may have played a role in the persistence of the osteoporosis.

COMMENT

Patients who have sustained trauma to an extremity usually have symptoms readily explained as the result of local tissue injury. A certain number, however, have superimposed upon these, other manifestations which can be interpreted only on the basis of some reflex activity initiated by the local trauma. Patients with vasomotor disorders of this kind may have an initial and transient period of hyperemia, or their difficulties may begin with signs of intense vasoconstriction. Later, the great majority show evidence of sympathetic hyperactivity. Primary manifestations in the acute stage are predominantly pain and swelling, although in a smaller number of patients coldness, hyperhidrosis, and cyanosis are more prominent. Later in the course of the illness the commonest complaints are swelling and pain on exercise and weight-bearing. Coldness, cyanosis, and hyperhidrosis are frequently noted and some suffer from distressing cold sensitivity. Many have edema which is present at rest, though it is more frequently noted when the limb is dependent. Persistent ulceration may be present when the skin is denuded.

A patient with a painful or edematous extremity, or an extremity which is the site of distressing coldness and hyperhidrosis, is strongly tempted to keep it at rest. Disuse itself may bring about a reduction in the blood flow with associated coldness, cyanosis, hyperhidrosis, edema, muscle atrophy, and osteoporosis. These are all alterations which are part of the post-traumatic

syndrome. Consequently, it is often difficult to evaluate the relative roles of the trauma and the reflexes initiated by it on the one hand, and of the resultant disuse on the other.

Continued disuse of the injured extremity also tends to bring about a rather fixed mental attitude which hampers return to normal activity. This factor may be the result of fear, discomfort, discouragement concerning recovery, or of some motivation to prolong the disability such as desire for compensation, avoidance of military duty, separation from service, or other rewards of invalidism.

Finally, emotional stress and instability, as well as certain of the more clear-cut psychiatric conditions, are often associated with increased sympathetic activity. Not infrequently those who have sustained an injury may bring such emotional and psychiatric mechanisms into play. Any casualty with a post-traumatic vasomotor disturbance must therefore be studied from this standpoint as well as from the purely physical.

Initial handling of the local injury should include such measures as debridement, removal of foreign bodies, reduction of fractures, and active treatment of infection. Although immobilization and bed rest should be utilized when they are indicated, early mobilization is advisable in most instances. Some patients, in fact, can prevent the post-traumatic syndrome, or overcome it when it develops shortly after injury, by simple persistence in forced active exercise. It is essential to instill in the patient confidence in his ability to make a satisfactory recovery, to eliminate any tendency toward chronic invalidism, and to correct any coexisting psychiatric ailment.

In many individuals, however, the difficulty cannot be alleviated so simply. In some of these such a procedure as direct blocking of the sympathetic pathways by procaine infiltration produces markedly beneficial effects. Not infrequently, as soon as the injection is completed, pain and hypesthesia disappear, temperature and color return to normal, and motor function is restored. If a foot is involved, it is not unusual to find that after sympathetic blocks the patient can immediately bear weight and walk normally. In many persons a single injection will suffice, while in others a series of treatments is necessary. If a beneficial, but only transient, effect follows sympathetic anesthesia, it is quite possible that sympathectomy will produce a complete cure. Periarterial sympathectomy has been suggested for milder cases. In certain patients in whom the site of local irritation, such as a painful scar or a thrombosed vessel is clearly evident, good results follow excision of the trigger points which might propagate the reflex disturbance. Sometimes local infiltration of procaine in the region of the injury results in dramatic improvement; this method is possibly also of value in preventing the development of post-traumatic disturbances.

In the treatment of the later stages of post-traumatic vasomotor disorders, the situation is complicated both by the fixed mental attitude of the patient

which is that of the chronic invalid, and by the extensive atrophy and motor weakness which result not only from the initial injury but also from the superimposed disuse. It is important to utilize psychotherapy in encouraging continued and gradually increasing active exercise of the affected limb and to employ more specific psychotherapeutic measures in those instances in which psychiatric factors are an accompaniment of, if not the primary basis for, the disability. Regardless of any other type of treatment, it is important to avoid edema by a period of bed rest with elevation of the limb and, if necessary, by the use of an elastic support.

In general, sympathetic blocks have little therapeutic value when the syndrome is of long duration, but may prove very useful in some patients, particularly those in whom edema is the primary manifestation or in whom evidence of increased sympathetic activity is predominant.

If the measures outlined have been tried faithfully and yield unsatisfactory results, sympathectomy should be considered. If the patients are properly selected, results are usually excellent.

Although numerous individual reports testify to the value of various therapeutic measures in the management of post-traumatic vasomotor disorders, it is impossible to establish from the data recorded in the literature the incidence of failures with the various methods of treatment. Experience with both military and civilian patients, however, emphasizes the importance of evaluating carefully all possible therapeutic aids in any given patient and of neglecting no useful adjuvant in treatment.

The group of patients analyzed in this chapter were all individuals in whom sequelae of trauma persisted and who required prolonged hospitalization for vasomotor disorders. It is significant that initial therapy, except in two patients in whom sympathetic blocks were carried out promptly, included none of the procedures listed as desirable under the circumstances. One patient experienced steady improvement following two blocks during the second week after injury and had few sequelae when seen some months later. The other had transient benefit from the single block carried out on the day of injury and significant, lasting improvement from several blocks carried out several months later.

An analysis of a group of military personnel has decided advantages. Military regulations afforded the opportunity to follow these patients carefully for as long a period of hospitalization as was required. Furthermore, in all patients in this series the same motive was present with regard to the rewards which might possibly arise from continued disability. Analysis of a comparable group of civilian patients is much more difficult. Such patients differ considerably in age and also in the factors which tend to make the persistence of complaints profitable or futile. Most civilians are necessarily hospitalized for as brief periods of time as possible and observations upon them limited to those intervals and to office visits. In general, however, experiences

with civilian and military patients complement one another. The manifestations of the post-traumatic disorders and the results of their treatment have been much the same in both military and civilian groups.

The chief point of interest in regard to therapy which emerges from this study is that the degree and duration of physical disability associated with post-traumatic vasomotor disorders are dependent in large part upon the amount of time that elapses between the onset of the condition and the initiation of active and adequate therapy. In most patients in this series early therapy was negligible and ineffective and, as a result, distressing sequelae persisted for many months and necessitated prolonged hospitalization. In contrast to the long period of hospitalization in these patients is the generally satisfactory course of events in civilian patients who are treated actively soon after injury. The period of incapacity is usually much shorter in civilian patients, especially when possible financial compensation is not a factor.

In the treatment of the late manifestations of post-traumatic vasomotor disorders the duration of therapy is necessarily longer than in the early phases and a more intense program of treatment is required. In addition, there is considerably less likelihood of a completely successful outcome and of the disappearance of all symptoms.

CHAPTER XVI

Sympathectomy in Circulatory Disturbances of the Extremities

Norman E. Freeman, M. D.

Sympathectomy was not a part of the therapeutic armamentarium in World War I because it had been used in man only occasionally and tentatively up to that time.¹ Since then large series of cases have been reported from civilian practice giving the indications for the operation, the technical methods, and the results to be expected. Significant data concerning the operation were gathered from the military experience in World War II particularly because of the concentration of patients with vascular injuries and disturbances into centers for specialized treatment. The unequalled wealth of clinical material thus provided served to confirm and reemphasize certain concepts of the value of sympathetic denervation in the treatment of circulatory disturbances of the extremities.

GENERAL INDICATIONS

There are two chief reasons for the employment of sympathetic denervation of the extremities, namely, the prevention of vasoconstriction and the relief of pain. The importance of sympathectomy in the prevention of vasoconstriction is apparent from Ochsner's statement² that the prognosis in any patient with peripheral arterial disease depends upon the degree of vasospasm because the therapy largely concerns the relief of vasospasm. As to the relief of pain, although the exact mechanism by which pain in the extremities is relieved by interruption of sympathetic pathways is still not clear, the fact that many patients are thus greatly relieved has been accepted by most surgeons working in the field.

A third, though much less frequent, indication for sympathectomy is the control of hyperhidrosis. Excessive sweating is due to abnormal activity on the part of the sympathetic nervous system and occasionally may become so incapacitating that surgical intervention is required. This is particularly true in instances of deficient circulation associated with vasospasm in the extremities. Hyperhidrosis may at times constitute a serious disability, chiefly because the resulting maceration of tissues predisposes them to infection.

¹ Ochsner, A., and DeBakey, M.: Peripheral vascular disease; critical survey of its conservative and radical treatment. *Surg. Gynec. & Obst.* 70: 1058-1072, Jun 1940.

² Ochsner, A.: Indications and technic for the interruption of impulses traversing the lumbar sympathetic ganglia. *S. Clin. North America* 23: 1318-1334, Oct 1943.

INCIDENCE

Most of the 887 sympathectomies performed at the three vascular centers in the Zone of Interior during World War II were carried out on the basis of one or the other of the indications just listed. The 672 patients upon whom the operations were performed were all males and over 60 percent were in their twenties. The figures from Ashford General Hospital are typical: The average age of the patients subjected to operation there was about 22 years, the age range 19 to 38 years.

Six hundred seventy operations were lumbar ganglionectomies and 217 were upper thoracic preganglionic sympathetic ramisectomies. Sympathectomy was performed for 1 extremity in 472 patients, for 2 extremities in 190 (bilateral), for 3 extremities in 5, and for all 4 extremities in 5 patients.

Lumbar Sympathectomy. The indications for which lumbar sympathectomy was performed, and the proportionate distribution of cases, were as follows:

Trenchfoot and frostbite, with or without gangrene, 43 percent.

Thromboangiitis obliterans of the lower extremities, 19 percent.

Vascular insufficiency, 19 percent. This group included patients with impaired circulation following ligation of major peripheral arteries; patients with arterial occlusion resulting from arteriosclerosis, thrombosis, and embolism; and patients on whom prophylactic sympathetic denervation was performed in order to facilitate the development of collateral circulation prior to excision of aneurysms of arteriovenous fistulas.

Raynaud's disease and vasospastic states, 10 percent. This group included not only patients with true Raynaud's disease but also those who complained of sensitivity of cold; those suffering with post-traumatic vasospastic states in which the factor of abnormal arterial vasoconstriction had been the primary reason for surgery; and those suffering from miscellaneous conditions such as acrocyanosis, hyperhidrosis, and scleroderma.

Pain, 8 percent. The majority of the patients in this group were suffering from causalgia and from post-traumatic osteoporosis (Sudeck's atrophy).

Thrombophlebitis, 1 percent.

Thoracic Sympathectomy. The indications for which thoracic sympathectomy was performed, and the proportionate distribution of cases, were as follows:

Raynaud's disease and vasospastic states, 36 percent.

Vascular insufficiency, 35 percent.

Causalgia and other conditions associated with pain, 23 percent.

Thromboangiitis obliterans of the upper extremity, 6 percent.

PREOPERATIVE TESTING

The vascular centers were equipped with facilities for special diagnostic tests for the evaluation of the circulatory status of patients with disturbances

of the peripheral circulation. In most instances, prior to sympathectomy, measurements of the skin temperature by means of thermocouples were made in constant temperature rooms, and pulsations of the peripheral arteries were determined by means of the oscillogram. The capacity of the blood vessels to dilate following release of vasoconstrictor tone was also observed.

The chief indication for sympathectomy, as already noted, is abnormal vasoconstriction or vasospasm. Vasoconstriction is the normal physiologic response of the body to cooling. It occurs both in normal patients and in those with diseased or injured blood vessels. The diagnosis of an abnormal degree of vasoconstriction is simple in such conditions as Raynaud's phenomenon, for instance, in which so-called digital syncope can usually be produced by exposure of the patient to a cold shower, but in less severe cases it is far more difficult to reach a conclusion and diagnostic measures have developed only gradually.

Brown,³ in 1926, was the first to approach the problem of placing vasomotor tone in man on a quantitative basis by comparing the rise in the skin temperature of the digits with the rise in the oral temperature after the administration of typhoid vaccine; the change in the surface temperature of the foot provided the index of vasodilatation. White,⁴ in 1930, used paravertebral injection of procaine hydrochloride to block the sympathetic nerves to the extremity as a test to evaluate the benefit of sympathetic ganglionectomy. Morton and Scott,⁵ in 1931, used general, spinal, and local anesthesia to release vasomotor tone and designated the average maximum vasodilator response for healthy arteries as "the normal vasodilatation level." Gibbon and Landis,⁶ in 1932, differentiated vasospastic from occlusive arterial disease by the vasodilatation with associated rise in the skin temperature which occurs upon heating unaffected extremities or portions of the body.

The tests described, which are based on the vasodilating capacity of the extremity, are useful in estimating the degree of organic vascular occlusion present in a patient, but they do not indicate the relative degree of vasoconstriction which intermittently or constantly affects the blood supply to the peripheral tissues. In order to make the diagnosis of abnormal vasoconstriction in this series, it was necessary, therefore, to utilize certain clinical signs.

The combination of peripheral cyanosis, increased sweating, and constriction of the superficial veins of the extremities used by Freeman and Montgomery⁷ as clinical evidence of high vasomotor tone proved useful at the vascular centers in the selection of patients with intermittent claudication

³ Brown, G. E.: Treatment of peripheral vascular disturbances of the extremities. *J. A. M. A.* 87: 379-383, 7 Aug 26.

⁴ White, J. C.: Diagnostic blocking of sympathetic nerves to extremities with procaine; test to evaluate the benefit of sympathetic ganglionectomy. *J. A. M. A.* 94: 1382-1383, 3 May 30.

⁵ Morton, J. J., and Scott, W. J. M.: Methods for estimating the degree of sympathetic vasoconstriction in peripheral vascular diseases. *New England J. Med.* 204: 955-962, 7 May 31.

⁶ Gibbon, J. H., Jr., and Landis, E. M.: Vasodilatation in lower extremities in response to immersing forearms in warm water. *J. Clin. Investigation* 11: 1019-1036, Sep 1932.

⁷ Freeman, N. E., and Montgomery, H.: Lumbar sympathectomy in treatment of intermittent claudication; selection of cases by claudication test with lumbar paravertebral procaine injection. *Am. Heart J.* 23: 224-242, Feb 1942.

for sympathectomy. It was recognized, however, that a more objective method was desirable.

White and Smithwick,⁸ on the basis of variations in surface temperature of the extremities in patients exposed to low room temperatures (20° C.), differentiated "cold handed" from "hot handed" individuals. Naide,⁹ on the basis of skin temperature changes during the cooling period and subsequent vasodilatation stage of the test described by Gibbon and Landis,¹⁰ devised a quantitative test for basal vascular tone. Later he found it necessary to note only the response of the digital skin temperature of the hands to the preliminary cooling in order to separate their patients into those with a high degree of vascular tone and those with a normal or low tone. He advocated the use of this test in the selection of patients for sympathectomy because he found that while the collateral circulation after major arterial occlusion was excellent in 88 percent of his patients with low vascular tone, equally good circulation was present in only 34 percent of those with high tone.

Forty-five patients with arterial injuries were studied by this test at DeWitt General Hospital prior to sympathectomy. The results were in agreement with the clinical evidence in 32 but did not conform with it in 13 patients. The results of operation indicated that the tests were valid in 20 patients, but in 11 others subsequent events showed that it had been misleading. In the remaining patients restoration of the continuity of the artery made post-operative evaluation by this method impossible. In this same group of 31 patients the end results in 26 were what might have been expected from a study of the clinical signs of abnormal vasoconstriction. Naide's test was frequently of value in confirming the clinical evidence of high vasomotor tone though it was occasionally misleading, and only rarely was it of diagnostic significance.

A possible explanation of the discrepancy between the results of the cold test and the impression gained on clinical observation is that the physiologic stimulus present at the time the examinations were made in the hospitals, such as excitement or a mild emotional disturbance, differed from the stimulus present during exposure to cold. Another possible explanation is differences in the type of stimulus used. Finally, since the arterial occlusion in each case resulted from trauma, it is quite within reason that reflex vasoconstriction might have been set up in the region supplied by the injured vessels; this is a purely local phenomenon which might be quite unaffected by the general vasomotor tone of the upper extremities as measured by the test.

The experience at the vascular center of DeWitt General Hospital with this and the other tests listed led to the conclusion that a valid qualitative

⁸ White, James C., and Smithwick, Reginald H.: *The Autonomic Nervous System*. 2nd ed. New York, The Macmillan Company, 1941.

⁹ Naide, M.: Test for vascular tone in humans and its application to the study of vascular diseases with special reference to the etiology and prevention of thrombophlebitis. *Am. J. M. Sc.* 207: 606-620, May 1944.

¹⁰ See footnote 6, p. 424.

test for the diagnosis of abnormal vasoconstriction was still to be developed. Experience at the other centers were to the same effect.

OPERATIVE TECHNIQUE

Lumbar Sympathectomy

All lumbar sympathectomies at the vascular centers in the Zone of Interior were carried out through an extraperitoneal approach. At both Ashford General Hospital and Mayo General Hospital, the operation was performed through a transverse, anterior, muscle-splitting incision. At DeWitt General Hospital a similar approach was used, with incision of the muscles of the abdominal wall.¹¹ Spinal analgesia was used in all but a few cases, and in those endotracheal nitrous-oxide-oxygen anesthesia was employed.

Atlas,¹² who made a careful study of the anatomic variations of the lumbar sympathetic nerves, found that a ganglion is constantly present lying on the disc between the second and third lumbar vertebrae and noted recurrence of sweating along the medial side of the foot when it was not removed. This observation was borne in mind in sympathectomies performed at the vascular centers, and in all the second and third lumbar ganglia, with the intervening chain, were excised. Occasionally the first or the fourth lumbar ganglion was also removed.

In the large series of operations reported from Mayo General Hospital the patients were given a regular diet and allowed to be up on the day after operation. The period of disability was considerably longer following the more extensive muscle-cutting procedure.

Thoracic Sympathectomy

All upper thoracic or dorsal sympathectomies performed at the vascular centers were, in reality, preganglionic sympathetic ramisectomies, since the ganglia were not removed but were simply decentralized. At Ashford and Mayo the posterior muscle-splitting incision was used. The operation was done by the technique advocated by Smithwick,¹³ according to which the roots of the second and third intercostal nerves are severed either within, or just outside of, the dura, while the sympathetic chain is divided below the third dorsal ganglion. The upper portion of the sympathetic chain, together with the decentralized second and third thoracic ganglia, is then sutured to the muscles outside of the thoracic cage in order to forestall regeneration.

In the patients operated on at Mayo General Hospital root section was occasionally omitted. It was carried out in all patients at the other centers. No differences in clinical results were noted.

¹¹ Harris, R. I.: Rôle of sympathectomy in treatment of peripheral vascular disease. *Brit. J. Surg.* 23: 414-424, Oct 1935.

¹² Atlas, L. N.: Sympathetic denervation limited to the blood vessels of the leg and foot. *Ann. Surg.* 116: 476-479, Sep 1942.

¹³ Smithwick, R. H.: Problem of producing complete and lasting sympathetic denervation of the upper extremity by preganglionic section. *Ann. Surg.* 112: 1085-1100, Dec 1940.

At DeWitt General Hospital preference was given to the anterior approach first described by Royle and later adapted by Gask ¹⁴ and by Telford ¹⁵ in England, and by De Takats ¹⁶ in this country. The sympathetic chain is exposed behind the pleura through a supraclavicular incision and is divided below the third thoracic ganglion. The connections of the second and third ganglia are then cut and the decentralized chain sutured to the upper end of the scalenus anticus muscle.

Endotracheal nitrous oxide-oxygen-ether was the anesthetic of choice for this operation. The postoperative discomfort and period of disability were shorter following thoracic sympathectomy through the anterior supraclavicular approach than after the dorsal operation.

SYMPATHECTOMY IN PERIPHERAL VASCULAR DISTURBANCES

Trenchfoot and Frostbite

At the time patients with trenchfoot and frostbite were observed at the vascular centers, which was always several weeks after the initial incident, the acute inflammatory reaction characteristic of these conditions had usually subsided and only disabilities resulting from damage to the soft tissues, peripheral nerves, and blood vessels remained.

In most instances skin temperature and oscillometric determinations were made, while studies of the response to paravertebral injection of procaine were found to be especially useful in the selection of patients for sympathectomy. The criteria for operation used at Ashford General Hospital, which were much the same as those prevailing at the other centers, included diminution in arterial pulsations at the foot level as determined by oscillometer, skin temperature constantly below 79° F., and constant cyanosis and sweating of the feet.

Generally speaking, results obtained from sympathectomy were both subjectively and objectively beneficial in patients thus selected. In a detailed analysis of one series of 55 patients with trenchfoot and frostbite it was found that in 35, with gangrene, lumbar sympathectomy had been performed in 10 instances bilaterally. Though healing ultimately occurred in all 35, most of the patients required minor amputations and some, various types of skin grafts. Eleven of the 20 patients without gangrene were also treated by sympathectomy of both lower extremities. In this group the complaints of coldness, cyanosis, and annoying sweating of the feet were relieved by the operation, but as a rule complaints of pain and tenderness, present in three-fourths of the patients, were not relieved.

The results of sympathectomy at the vascular centers suggest that the residual hyperactivity of the sympathetic nervous system following trauma from cold (in addition to the actual destruction of tissue) and characterized

¹⁴ Gask, G. E.: Surgery of the sympathetic nervous system. Brit. J. Surg. 21: 113-130, Jul 1933.

¹⁵ Telford, E. D.: Technique of sympathectomy. Brit. J. Surg. 23: 448-460, Oct 1935.

¹⁶ De Takats, G.: Effect of sympathectomy on peripheral vascular disease. Surgery 2: 46-60, Jul 1937.

by vasospasm, increased sweating, and sensitivity to cold can be relieved by this method. On the other hand, pain and tenderness, which are probably secondary to tissue trauma, usually do not respond to sympathectomy.

Thromboangiitis Obliterans

Before any patient with thromboangiitis obliterans was selected for sympathectomy, his vascular status was determined by means of the oscillometer with skin temperature measurements. Special attention was also paid to the capacity of the collateral vessels to dilate after release of vasomotor tone following spinal analgesia and paravertebral block. In a few patients with marked circulatory impairment, although increase in skin temperatures was slight, considerable improvement in the condition was noted after sympathectomy. As White¹⁷ commented, wide clinical experience is essential in selecting the patients for operation from the small group in which sympathectomy has been shown by experience to be sometimes surprisingly worthwhile even though preliminary tests do not indicate a striking relief of vasospasm. Harris,¹⁸ in harmony with this concept, wrote that it was his practice to use lumbar sympathectomy in all severe cases of thromboangiitis obliterans regardless of the results of the preoperative tests.

In the vascular centers it became more and more the tendency in the selection of patients for sympathectomy in cases of thromboangiitis obliterans, to rely on clinical evidence of abnormal vasoconstriction, as shown by cyanosis, sweating, and the presence of constricted veins. Demonstrations of improvement in the ability of the patient to walk after paravertebral block was particularly useful in the selection of individuals for early operation.

At Ashford General Hospital the indications for sympathectomy were eventually crystallized about as follows: (1) Evidence of a large vasospastic element characterized by cyanosis, coldness, and sweating. (2) Pain, constantly present. (3) Quantitative elevation of temperature after spinal analgesia or sympathetic block. (4) The presence of ulcers or gangrene. At the other centers the indications for sympathectomy were essentially the same. In numerous instances at all centers the indications were multiple.

Resection of the sympathetic ganglion was carried out for 1 extremity in 33 of the 152 patients with thromboangiitis obliterans whose records were available for this analysis, and for 2 extremities (bilateral) in 18 patients. The operation was also performed in 2 of the patients in whom 3 extremities were affected. Good results were observed in all. Gangrenous areas demarcated and separated promptly and healing was rapid. Ulcers also healed. Resting pain was relieved or partially relieved. Functional capacity, particularly the ability to walk, was greatly increased. Oscillometric readings and measurements of skin temperatures furnished objective evidence of subjective improvement.

¹⁷ White, J. C.: Progress in surgery of the autonomic nervous system, 1940-1942. *Surgery* 15: 491-517, Mar 1944.

¹⁸ Harris, R. I.: Obliterative vascular disease; treatment by sympathectomy. *Canad. M. A. J.* 45: 529-533, Dec 1941.

Minor amputations were necessary in 12 of the patients treated by sympathectomy on the indication of thromboangiitis obliterans, but only 3 of the 53 patients were not improved at all. Major amputation of the leg was required in 2 of these unimproved patients, but in 1 instance it was necessary because of contractures about the knee and ankle and not because of the vascular disease per se. It is of interest that the 3 patients who were not at all improved by sympathectomy had all continued to smoke in spite of advice and prohibitions to the contrary.

There was general agreement in all the vascular centers that sympathectomy is the treatment of choice in thromboangiitis obliterans, especially in the more severe cases. The disease is frequently associated with abnormal vasoconstriction, and the circulation will be improved to the extent that circulatory deficiency can be relieved by removal of this added factor. On the other hand, De Takats'¹⁹ warning should be heeded: "Sympathectomy deprives the extremity of its vasoconstrictor tone. It does not influence the course of Buerger's disease." In other words, as long as obliteration of blood vessels continues to recur, the disease may be improved or arrested, but it cannot be said to be cured.

Raynaud's Disease and Vasospastic States

In the group of patients with Raynaud's disease and other vasospastic conditions, study of the circulation after removal of vasomotor tone was of great significance as a preoperative test. In 1 group of 57 patients the response to paravertebral block was used for this purpose in 37, the effects of spinal anesthesia were observed in 17, and the results of the vasodilatation test (reflex heat) were used in 3 patients. Differentiation was made between patients with true Raynaud's disease and other vasomotor disorders on the basis of the production of actual spasm of digital arteries characterized by digital syncope on immersion of the entire body for 2 minutes in a cold shower. It was sometimes observed that digital syncope was not produced by this procedure even though characteristic attacks were occasioned in cold weather. The occurrence of typical attacks was therefore considered more significant than the results of the test. The urgency of the indications for sympathectomy depended upon the severity and frequency of arterial spasm, especially if destruction of the digital pulp had occurred or was impending. When cold sensitivity and frequency of attacks were incapacitating, sympathectomy was regarded as mandatory.

At Ashford General Hospital considerable improvement was noted in all 30 patients upon whom sympathectomy was performed for Raynaud's disease. This operation was carried out for involvement of 1 extremity in 2 patients, of 2 extremities (bilateral) in 23, of 3 extremities in 2, and of 4 extremities in 3 patients. Although after operation digital syncope could still be elicited by

¹⁹ De Takats, G.: Value of sympathectomy in the treatment of Buerger's disease. *Surg., Gynec. & Obst.* 79: 359-367, Oct 1944.

the cold shower test, it was considerably diminished in degree, extent, and duration. Within 3 to 5 weeks of operation definite evidence of partial resumption of vasomotor tone in the upper extremity, which could be prevented by blocking the peripheral nerves with procaine, was noticed in 2 patients subjected to multiple procedures. The experience at Ashford General Hospital is in harmony with that reported by the other centers.

Although patients with Raynaud's disease of the upper extremities were considerably improved by sympathectomy, they were not cured and none could be returned to duty. Results observed after sympathectomy of the lower extremities were, as expected, better than those obtained by operation on the upper extremities. This difference is probably to be explained by the anatomic arrangement of the vasoconstrictor nerves to the upper, in comparison with the lower, limbs.

Post-traumatic Vasospastic States. Patients with post-traumatic vasospastic states had a variety of complaints of which vasospasm, edema, and pain were the most common. This group was differentiated from patients with causalgia, post-traumatic painful osteoporosis (Sudeck's atrophy), and various reflex dystrophies chiefly on the basis of clinical evidence of abnormal vasoconstriction. They are discussed in Chapter XV.

Causalgia

Paravertebral injection of procaine into the region of the thoracic or lumbar sympathetic ganglia was the one really significant preoperative diagnostic test in selection for sympathectomy of patients who were suffering from causalgia and other painful conditions of the extremities. The prompt relief of pain after the injection was usually striking and conclusive. Skin temperature and oscillometric determinations were significant only in demonstrating that the sympathetic block had been successful. Subsequent sympathectomy was generally effective in relieving the condition. Equally good results were obtained in patients with pain in either the upper or the lower extremity. Of the 57 patients treated for causalgia by sympathectomy at Mayo General Hospital, excellent results were reported in 46, and good effects in 9. In 2 patients the end result was described as fair or poor. Sympathectomy was performed chiefly because of pain in the extremities in 60 patients at Ashford General Hospital. The operation was almost uniformly effective in relieving this symptom.

The exact mechanism through which sympathectomy relieves pain in the extremities is not fully understood. The dramatic relief afforded by sympathetic block furnishes, however, strong clinical evidence to support the concept that nerves mediating painful sensations from the extremities actually traverse the sympathetic ganglia. Attempts to demonstrate their presence, whether by anatomic studies or by physiologic investigations, have generally been unsuccessful, although some observations in this field are promising. In order to

explain the clinical observations other concepts have been advanced. Lewis²⁰ suggested that the relief of pain after sympathectomy is the result of the persistently increased blood flow through the cutaneous vessels consequent upon loss of vasomotor tone. The essential disturbance, according to Livingston,²¹ is a "central perturbation of function involving the spinal cord centers"; he also suggested that the "sympathetic nerves may contribute to the development of peripheral tissue changes, which may lead to additional afferent impulses."

Both of these explanations are based on the concept that relief of pain in causalgia depends on paralysis of *efferent* sympathetic nerves with consequent loss of vasomotor tone. Clinical evidence, however, suggest that the relief observed depends on the suppression of *afferent* sensory stimuli. Only the failure of experimental investigation to reveal the transmission of pain stimuli from the extremities across sympathetic ganglia prevents the acceptance of the simpler explanation which accords so readily with clinical observations.

Probably the most reasonable explanation of causalgic pain is that advanced by Doupe²² and coworkers who ascribe its peculiar qualities to direct cross stimulation of sensory fibers by efferent sympathetic impulses at the point where the nerve trunk is injured, rather than to the indirect action of the vasoconstrictor response which they also produce. Final explanation of the mechanism of the relief achieved in causalgia and other painful conditions of the extremities by sympathectomy or by injections of procaine around the sympathetic ganglia must await further experimental evidence. There was general agreement in the vascular centers, however, that sympathectomy, whatever the mechanism, was quite effective in the treatment of these painful conditions.

Vascular Insufficiency

Records show that in the category of vascular insufficiency were included (1) those patients with impaired circulation following ligation of major vessels of the extremity, (2) those in whom arterial thrombosis developed at the site of trauma, and (3) those in whom sympathectomy was performed as a prophylactic measure prior to operation for arterial lesions. Sympathectomy was performed in well over half of these patients for symptoms arising from obstruction of the main arterial supply to the limb. Preoperative tests included skin temperature and oscillometric determinations, also observation of the vascular supply after spinal analgesia or paravertebral block.

The chief indications for sympathectomy in patients in the first two categories were impaired circulation, nerve paralysis, gangrene, and ulceration. The results of sympathectomy in this group were extremely satisfactory. In spite of the severe impairment of circulation, improvement was noted in all patients. Ulceration and gangrenous areas healed although minor amputations

²⁰ Lewis, Thomas: *Pain*. New York, The Macmillan Company, 1942.

²¹ Livingston, William K.: *Pain Mechanisms. A Physiologic Interpretation of Causalgia and Its Related States*. New York, The Macmillan Company, 1943.

²² Doupe, J.; Cullen, C. H., and Chance, G. Q.: Post-traumatic pain and the causalgic syndrome. *J. Neurol., Neurosurg. & Psychiat.* 7: 33-48, Jan-Apr 1944.

and skin grafts were necessary in some. Satisfactory progress in nerve recovery took place. Amputation of the extremity was ultimately necessary in only 2 patients, in 1 of whom circulatory impairment was not the cause; the operation was done for contracture and recurrent osteomyelitis.

The chief indications for sympathectomy after excision of aneurysms or arteriovenous fistulas were sensitivity to cold, nerve damage, impaired circulation, and pain. In all instances cold sensitivity and pain were relieved by operation. Improvement in the function of peripheral nerves also resulted. Amputation was necessary in only one patient; thrombosis of the collateral vessels developed after excision of a femoral arteriovenous aneurysm. The circulation improved following sympathectomy, but gangrene of the foot developed later and amputation became imperative.

Ninety-three of the 155 sympathectomies available for analysis and categorized as operations for vascular insufficiency were performed for prophylactic reasons in order to facilitate the development of collateral circulation before operation. In spite of the arterial lesions circulation was adequately maintained in the majority of the patients before operation, but there were 2 instances of gangrene and 5 others in which circulation was impaired. Associated nerve damage was present in 25 patients but in all improvement followed sympathectomy.

The chief indication for sympathectomy in the group of prophylactic operations was poor collateral circulation as determined, prior to excision of the arterial aneurysm or arteriovenous fistula, by the Matas-Moschcowitz test: The main artery was temporarily occluded at the site of the arterial lesion, the distal tissues were rendered ischemic for 5 minutes by an Esmarch bandage, and the time necessary for flushing of the extremity after release of the bandage, noted. The collateral circulation was regarded as good if, while the main artery was still occluded, color returned to the distal portion of the extremity in 60 seconds or less. If flushing was delayed more than 3 minutes, the collateral circulation was considered unsatisfactory.

In the patients in this group observed at DeWitt General Hospital the average time required for color to return to the extremity before sympathectomy was 3 minutes and 15 seconds. After the operation the time was reduced to 45 seconds. Definite improvement in the collateral circulation, as determined by the fluorescein wheal test, was also noted in these patients.

The indications for sympathectomy following traumatic or therapeutic occlusion of major arteries gave rise to no differences of opinion when actual gangrene or ulceration, ischemic paralysis, pain, and other results of impaired circulation were present. All of these are conditions known to be greatly improved by sympathectomy. They may also be prevented if sympathectomy is performed as soon as vascular impairment becomes evident, as advocated by Learmonth²³ in the treatment of acute vascular injuries. In two patients

²³ Learmonth, J. R.: Surgery of blood vessels. *Edinburgh M. J.* 47: 225-240, Apr 1940.

included in this series the foot became extremely ischemic after ligation of the popliteal artery for an arterial lesion. Sympathectomy was performed immediately, in each instance while the patient was still under the original anesthetic, and results in both patients were excellent.

There was not complete agreement at the vascular centers, however, over the advisability of sympathectomy as a prophylactic procedure either before or after excision of aneurysms and arteriovenous fistulas. The surgeons at Mayo General Hospital and DeWitt General Hospital were in favor of the procedure. The surgeons at the vascular center of Ashford General Hospital were not. In contrast to 149 operations performed for vascular insufficiency at Mayo and DeWitt General Hospitals, only 6 of the 469 sympathectomies performed at the Ashford center were for this condition. Elkin, at Ashford, has repeatedly stated that it is his personal belief, based on experience, that sympathectomy is not necessary in such cases if sufficient time has been allowed to elapse for a collateral circulation to develop. In his opinion,²⁴ "It is an assumption, and nothing more or less than that, that gangrene is prevented by sympathectomy." His extensive experience in vascular surgery makes it quite clear that sympathectomy is not required to prevent gangrene, and there were no instances of it following excision of aneurysms or arteriovenous fistulas at the Ashford General Hospital where interruption of the sympathetic pathways has been omitted.

On the other hand, in spite of the Ashford experience, the question arises as to the degree of vascular insufficiency which persists after operation. The collateral circulation in the patients managed at that hospital without sympathectomy may have been quite adequate to maintain tissue nutrition while they were at rest so that gangrene did not develop after operation, but whether it was sufficient to permit normal activity after they left the hospital is another matter. The improvement noted at the other centers after sympathectomy in patients who had undergone ligation of major arteries, and in others who complained of symptoms of vascular insufficiency after excision of arterial lesions, indicated the value of this procedure in these circumstances. Bigger's²⁵ experience may also be cited in this connection. He wrote:

In the literature dealing with the treatment of traumatic vascular lesions of important blood vessels, much is said, and properly, about the cure of the lesion and the avoidance of acute ischemic gangrene, but remarkably little consideration is given to the permanent reduction of blood supply to the tissues, especially the muscles, distal to the lesion.

Bigger noted excellent immediate results following excision of arteriovenous fistulas when sympathectomy was omitted but found late results less satisfactory. Of 8 patients examined between 9 months and 8 years after operation, 7 had marked symptoms of chronic circulatory deficiency distal to the obstruction. Bigger therefore concluded that permanent interruption of

²⁴ Elkin, D. C.: Personal communication to the author.

²⁵ Bigger, I. A.: Treatment of traumatic aneurysms and arteriovenous fistulas. *Arch. Surg.* 49: 170-179, Sep 1944.

the sympathetic nerves to the extremity may help prevent chronic circulatory deficiency distal to the obstruction. Others share his opinion. Learmonth²⁶ advocated sympathectomy in all patients in whom permanent ligation of the femoral or popliteal arteries is expected and Gage and Ochsner²⁷ recommended chemical section of the sympathetic nerves before operations on major arteries.

Since the development of a collateral circulation determines the ultimate outcome in vascular operations involving ligations of major arteries to the extremities, and since abnormal vasoconstriction apparently interferes with the development of collaterals, sympathectomy should perhaps be reserved for those patients who show evidence of increased vasomotor tone. Prophylactic sympathectomy, although it increases the assurance of an adequate post-operative blood supply, might well be reserved for those patients in whom the location of the arterial lesions and the results of the preoperative tests indicate that severe disturbances of circulation may follow ligation of the major artery to the extremity. Even in those patients it might be justifiable to hold the operation in reserve and to perform it only in the event that arterial ligation leaves an incapacitating circulatory disturbance.

Unnecessary Prophylactic Sympathectomy. Though preoperative sympathectomy improves the collateral circulation in patients with aneurysms and arteriovenous fistulas upon whom vascular surgery is to be performed, prophylactic operation is not always necessary. Spontaneous closure of the fistula and spontaneous cure of an aneurysm may occur (see Chapter XII). Moreover, the main artery to the extremity may prove not to be the one involved, or subsequent arterial repair may be found to be possible.

Clinically satisfactory spontaneous closure of a subclavian arteriovenous fistula and spontaneous cure of a femoral arterial aneurysm were observed following sympathectomy at one vascular center and a case similar to the latter was observed at another center. Sympathectomy, however, cannot be given full responsibility for inducing the closure since spontaneous cures were recorded in similar cases in which sympathectomy was not carried out. It is self-evident that in these instances prophylactic sympathectomy was unnecessary. On the other hand, spontaneous cure of an aneurysm or spontaneous closure of an arteriovenous fistula may occasionally be followed by sufficient impairment of circulation to necessitate subsequent sympathectomy.

Inaccurate localization of an arterial lesion before operation may also lead to unnecessary sympathectomy. A branch rather than the main artery may be the vessel involved. This happened in several instances in this combined series. In 4 instances the lateral circumflex femoral or the profunda femoris artery was involved instead of the femoral artery. In 2 other instances a geniculate artery was involved instead of the popliteal as had been supposed. In still another instance the transverse cervical branch, instead of the sub-

²⁶ See footnote 23, p. 432.

²⁷ Gage, M., and Ochsner, A.: Prevention of ischemic gangrene following surgical operations upon the major peripheral arteries by chemical section of the cervicodorsal and lumbar sympathetics. *Ann. Surg.* 112: 938-959, Nov 1940.

clavian artery, was the site of the arterial lesion. In 1 case reported from a vascular center an arteriovenous fistula, which involved the arch of the aorta and the superior vena cava, could not be excised and sympathectomy of the left upper extremity was therefore performed unnecessarily.

Restoration of the continuity of the artery instead of excision of the lesion may also make preliminary sympathectomy unnecessary. In several instances of arteriovenous fistulas in this series, and in a small number of arterial aneurysms, successful repair of the arteries and restoration of the circulation rendered the prophylactic sympathectomy which had been performed quite superfluous. It may be argued that preliminary sympathectomy possibly contributed to the success of the arterial repair. In 8 patients, however, suture of the artery was successfully employed without preliminary sympathectomy, while in 2 instances, in both of which sympathectomy had been done, arterial repair was not successful.

Thrombophlebitis

Many patients with longstanding thrombophlebitis were referred to the vascular centers for treatment of the resulting disabilities which included cyanosis, sweating, diminished peripheral circulation, and pain. Temporary relief following paravertebral block suggested that lumbar sympathectomy might be of benefit in these patients. The value of this method in the early treatment of thrombophlebitis of the lower extremities, first advocated by Leriche and Kunlin,²⁸ had been well established before World War II by the subsequent studies of Ochsner and DeBakey.²⁹

Seven patients referred to the vascular centers for the treatment of late thrombophlebitis were treated by this method. Although the sweating and peripheral vasoconstriction present were abolished and pain was moderately relieved, congestion and edema caused by venous obstruction were not benefited. In 3 or 4 patients operated on at Ashford General Hospital on this indication, complaints of cyanosis, edema, congestion of the limb, and pain on walking were increased after the operation. The other patient was slightly improved. On the face of the evidence, therefore, sympathectomy does not seem of value in the treatment of the late residua of thrombophlebitis.

ANALYSIS OF RESULTS

The 887 sympathectomies performed in the vascular centers in the Zone of Interior were carried out without a single fatality attributable to the operation. This record may in part be ascribed to the fact that the patients were mostly young and healthy, and in part to the fact that sympathectomy has become a standardized procedure which, in the hands of well-qualified surgeons, should always carry small risk.

²⁸ Leriche, R., and Kunlin, J.: Traitement immédiat des phlébites post-opératoires par l'infiltration novocaïnique du sympathique lombaire. *Presse méd.* 42: 1481-1482, 22 Sep 34.

²⁹ Ochsner, A., and DeBakey, M.: Treatment of thrombophlebitis by novocain block of sympathetics; technique of injection. *Surgery* 5: 491-497, Apr 1939.

The possibility of sterility as the result of interference with ejaculation after bilateral lumbar sympathectomy might constitute a definite contra-indication to the performance of this operation, especially in young men. Ochsner³⁰ has maintained that bilateral resection of the first lumbar interferes with ejaculation, and White and Smithwick³¹ stated "After removal of the [superior hypogastric] plexus or injury to the first lumbar ganglia the power of ejaculation is lost," but added in a footnote "We are obtaining increasing clinical evidence that males may not be sterile or have any alteration of sexual function after bilateral excision of the first or even the upper three lumbar ganglia." In the majority of sympathectomies performed at the vascular centers, the first lumbar ganglion was not removed. Lake³² found in 2 patients normal numbers of spermatozoa after bilateral resection of the second, third, and fourth lumbar ganglia, and De Takats and Helfrich³³ reported similar findings after extensive bilateral lumbodorsal sympathectomy.

Particular attention was paid to this problem in studying the patients upon whom sympathectomy was performed. No patients complained of difficulty with ejaculation in the group reported from Mayo General Hospital. Three patients at Ashford General Hospital claimed temporary impotence but the bilateral operation had not been performed in any of them and it seems probable that the condition was on an emotional basis.

Complications and Sequelae. While it was inevitable that a certain number of incidental complications should have occurred, such as infections and hematomas in operative wounds, these were infrequent. Pneumothorax, once unilateral and once bilateral, followed thoracic sympathectomy in 2 instances. It was readily treated by aspiration of the pleural cavity. Inadvertent resection of the fourth rib instead of the third, during sympathectomy by the dorsal approach, led to incomplete denervation in 1 patient. Transient spinal radiculitis developed in 1 patient after dorsal sympathectomy.

Following lumbar sympathectomy a number of patients complained of pain in the thigh and of paresthesias in the distribution of the genitofemoral nerve. The incidence of this complication was reported as 25 percent from Ashford General Hospital and was about the same at the DeWitt General Hospital. On the other hand, it was notably lower at Mayo General Hospital—not more than 5 percent—and in only 2 patients did the pain persist for more than 10 days. The infrequent occurrence of this troublesome symptom at this center may possibly be explained by the more limited operative exposure which was used. The pain in the thigh, although annoying, disappeared spontaneously. Sweating of the body may be greatly increased after

³⁰ See footnote 2, p. 422.

³¹ See footnote 8, p. 425.

³² Lake, N. C.: Sympathectomy and sterility. *Brit. M. J.* 1: 843, 24 Jun 44.

³³ De Takats, G., and Helfrich, L. S.: Sterility of the male after sympathectomies. *J. A. M. A.* 117: 20-21, 5 Jul 41.

quadrilateral sympathectomy, with resultant paralysis of the sweat glands of all 4 extremities, and 2 patients complained of excessive perspiration after their operations.

After thoracic sympathectomy partial recurrence of vasospasm characterized by digital syncope was frequently observed, especially in patients with Raynaud's disease, when the cold shower test was given. This was not true of the patients upon whom the lumbar operation had been performed. This observation, which is in keeping with that of the majority of surgeons working in this field, has been the subject of considerable controversy. Lewis³⁴ noted that vasoconstriction still took place in the fingers after excision of the stellate and upper thoracic ganglia. He therefore ascribed the vasospasm in Raynaud's disease to "local fault," the assumption being that the blood vessels of the digits are abnormally sensitive to cold while the vasomotor reactions are normal. The possibility that the recurrent vasoconstriction is caused by sensitization of the blood vessels to circulating adrenalin as the result of sympathetic ganglionectomy was advanced by Freeman, Smithwick, and White.³⁵ It was to avoid this sensitization phenomenon that Smithwick³⁶ suggested the preganglionic type of sympathectomy which has now come to be so extensively practiced. Even after this operation, however, residual vasospasm is frequently noted in patients with Raynaud's disease. It was reported from all of the vascular centers.

The fact that blocking the peripheral nerves with procaine, as previously noted, was followed in two patients by noticeable elevation in temperature of the digits (an observation which confirms those of other investigators) indicates that there is some persistent innervation by vasoconstrictor fibers. Kuntz and Dillon³⁷ attributed residual vasoconstriction to efferent fibers arising from the first dorsal root, since they had found evidence of such neural pathways in the experimental animal. Ray, Hinsey, and Geohegan³⁸ showed by stimulation of the anterior roots in man that preganglionic impulses may be transmitted through the first dorsal root. Regeneration of preganglionic nerves has also been suggested as an explanation. Obviously, the problem of how to produce a lasting preganglionic denervation of the upper extremity is not yet fully solved.

³⁴ Lewis, T.: Experiments relating to the peripheral mechanism involved in spasmodic arrest of the circulation in the fingers, variety of Raynaud's disease. *Heart* 15: 7-101, Aug 1929.

³⁵ Freeman, N. E.; Smithwick, R. H., and White, J. C.: Adrenal secretion in man; reactions of blood vessels of human extremity, sensitized by sympathectomy to adrenalin and to adrenal secretion resulting from insulin hypoglycemia. *Am. J. Physiol.* 107: 529-534, Mar 1934.

³⁶ See footnote 13, p. 426.

³⁷ Kuntz, A., and Dillon, J. B.: Preganglionic components of the first thoracic nerve; their role in sympathetic innervation of the upper extremity. *Arch. Surg.* 44: 772-778, Apr 1942.

³⁸ Ray, B. S.; Hinsey, J. C., and Geohegan, W. A.: Observations on the distribution of the sympathetic nerves to the pupil and upper extremity as determined by stimulation of the anterior roots in man. *Ann. Surg.* 118: 647-655, Oct 1943.

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